A SMALL REVOLUTION IN SPACE:

AN ANALYSIS OF THE CHALLENGES TO US MILITARY ADOPTION OF SMALL SATELLITE CONSTELLATIONS

BY

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APPROVAL

The undersigned certify that this thesis meets masters level standards of research, argumentation, and expression.

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DISCLAIMER

The conclusions and opinions expressed in this document are those of the author. They do not reflect the official position of the US Government, Department of Defense, the United States Army, the United States Air Force, or Air University.

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ABSTRACT

This study explores the potential challenges to US military adoption of small satellite constellations into its space architecture. It begins by analyzing the different small satellite constellations that are currently being proposed or deployed on orbit. The history of US policy and acquisition strategies towards remote sensing systems and commercial satellite communications is then explored in detail. Case studies tracing the consolidation of the remote sensing industry down to just one company and the bankruptcy and reemergence of the first commercial satellite constellation, Iridium, are analyzed for lessons that can be applied to future acquisition strategies. Detailed analysis of the problems with current and historical approaches to acquiring both remote sensing and commercial satellite communications follow the historical study. The research concludes with recommendations on how to better posture the US military to properly leverage the emerging technology of small satellite constellations and the difficulties of denying their use to adversaries.

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Introduction

> *In the long haul our safety as a nation may depend upon our achieving 'space superiority.' Several decades from now the important battles may not be sea or air battles, but space battles, and we should be spending a certain fraction of our national resources to ensure that we do not lag in obtaining space supremacy.*
>
> -Major General Bernard Schriever address to the Astronautics Symposium in San Diego, February 19, 1957

The predictions made by General Schriever about the possibilities of war in space have thankfully not yet come true. Space is often considered the ultimate high ground in military circles, but early efforts in the space-race era resulted in a number of treaties that have prevented the weaponization of space. This has not, however, prevented space from being militarized through uses such as a relay for military communications, a location for early warning satellites, or a base from which to image the internal areas of other nations. Fear that this seeming militarization of space will spark conflict is common in political, media, and academic circles. Despite such fears, a strong argument can be made that these military-intelligence and communications satellites encourage peace by removing uncertainty about the intentions of other nations, making it easier for political leadership to communicate with subordinate commanders in real time, and promoting openness by making it difficult to hide anything of significance.

The US military has come to rely on space-enabled capabilities ranging from communications to the Global Positioning System (GPS), in order to achieve battlefield effectiveness. Many systems and units cannot function without space-enabled capabilities, and this has created a vulnerability that near-peer adversaries of the US and its allies are unlikely to ignore. This concern is captured in the often-cited language

of the *National Security Space Strategy* that describes space as becoming "increasingly, congested, contested, and competitive."[1]

Including the term "contested" among those three trends in the space domain highlights the vulnerability of the current US military space architecture. This architecture was built with the assumption that space was a sanctuary, but activities like the Chinese launch of a direct-ascent anti-satellite weapon in 2007 have challenged this assumption.[2] US military satellites commonly have launch and build costs in excess of a billion dollars, take decades to develop, and are relatively finite in number. Destroying a handful of satellites can have devastating consequences for US military capability in an entire region of the globe. Attempts to address this challenge have preoccupied the US military space community since China demonstrated its anti-satellite capability. Most of the proposed solutions are expensive and of only moderate effectiveness. A single target, no matter how you attempt to secure it, represents a vulnerable node that is impossible to defend against all threats. A new way of operating in space that does not rely on a single vulnerable satellite is needed to deter hostile action in space. Small satellite constellations represent a new, emerging technology that may solve this problem.

The last few years have seen a revolution in satellite and launch technology. This revolution has reduced the cost of access to space by an order of magnitude and seen the introduction of a highly capable class of small satellites. These two trends have created an opportunistic mindset in regard to space, particularly in the satellite-communications and imaging fields where small satellite constellations can provide advantages not possible to traditional providers. Google and Fidelity

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[1] 2011 National Security Space Strategy, Unclassified Summary, January 2011, i.
[2] Brian Weeden, "2007 Chinese Anti-Satellite Test Fact Sheet," *Secure World Foundation*. 23 November 2010, https://swfound.org/media/9550/chinese_asat_fact_sheet_updated_2012.pdf.

have invested $1 billion in a Space X global internet project and are in competition with Qualcomm and Sir Richard Branson's Oneweb. The imaging field has seen an even greater growth in investment and on-orbit capability. Terra Bella (Google), Omni-Earth, and Planet Labs already have systems on orbit and are quickly building out satellite constellations numbering in the hundreds. Currently, US military use of commercial space capability is seen as a gap-filler for dedicated military systems. In the near future, the capabilities and price competitiveness of commercial systems will exceed anything the US Government can produce. Whoever can exploit these systems may achieve information dominance from space. If the US military does not consider different approaches to effectively leveraging these capabilities, with their inherent benefits and costs, it may be overmatched by adversaries that do.

Purpose and Research Question

Given the current revolution in small satellite technology, this research assesses the US military's ability to leverage small satellite constellations into its existing architecture. Specifically, I consider how policies, developmental models, and purchasing agreements influence the utilization of emerging remote sensing and communications-constellation capabilities. I then suggest potential ways forward that position the US military to best adopt small satellite constellations in such a way as to maintain its warfighting advantages over its adversaries.

This research does not argue whether small satellite constellations are superior to traditional satellite systems. Both approaches have advantages and disadvantages that are unique to their orbits and architectures. What is true is that small satellite constellations are being launched, and they will provide alternatives to many existing capabilities that can address some of the existing vulnerabilities inherent in the current architecture. The only previous attempt at a commercial

constellation, Iridium, is a cautionary tale of technical overreach, unrealistic optimism, and ultimately massive bankruptcy that has held back any further attempts to build something on a similar scale. Developments in space and terrestrial technology have revitalized the possibilities inherent in distributed low-Earth-orbit constellations and represent an opportunity for the US military to make its architecture less susceptible to attack.

Methodology

Effectively assessing the issue of small satellite adoption requires an analysis of current and past policies with respect to commercial communications and remote sensing platforms as well as their level of effective applicability to emerging capabilities. For evidence of current and past policies towards commercial space systems I utilize a variety of government reports, briefs, and other documents. Secondary sources are limited to a handful of scholarly articles and books on acquisition and space policy. Additionally, I conducted a small number of interviews over email and phone with senior space policy makers in the Office of the Secretary of Defense as well as with the senior licensing officer with the National Oceanic and Atmospheric Administration (NOAA). Where available, I also utilize case studies of commercial space systems' history with the US Government and military. The criteria for answering the research questions embrace whether current space policy and acquisition systems have been effective in maximizing commercial space utilization and if these same processes posture the US military to capitalize on emerging space capabilities. If not, what changes to policy and purchasing models are needed for future success?

Thesis Organization

This research is broken into five parts, excluding this introduction. Chapter two introduces the existing and announced small satellite

constellations whose potential future impact is the impetus behind this research. I discuss the capabilities of the various constellations as well as the timelines and backers of the various projects. Complete data on every system is often not available since many of these systems are in the early stages of design, and even during the short course of this research, details have changed. Comparisons are made to existing systems with which these new capabilities will initially compete. I use the best available data at the time of this writing to develop the background information contained in this chapter.

Chapter three explores the history of policy and acquisition posture toward remote sensing platforms. The purpose of this chapter is to trace the development of the commercial remote sensing industry to demonstrate the key role that policy and acquisition factors have played in delaying the successful development of a commercial remote sensing industry. Two case studies are included in this chapter to highlight specific policy and acquisition effects. The first is a study of the consolidation of the remote sensing industry over the course of two decades to just one company. This was the result of dependence on government business and poorly crafted laws that limited commercial opportunities. The second case study looks at how specific national security concerns led to policies that prevented the development of a radar-based remote sensing industry in the US. This chapter also includes an overview of US Government strategies to prevent adversary access to the data produced by remote sensing platforms.

Commercial satellite communications receive a similar treatment in the fourth chapter. The primary purpose of this chapter is to determine how the US military has acquired commercial satellite communications historically and how that is changing. The US military's relationship with Iridium, the sole commercial small satellite communications constellation active today, is used as a case study. Pathfinder and other

evolving efforts to improve acquisition of satellite communications capabilities are also discussed in detail.

The fifth chapter of this research uses the information gleaned from the research in the preceding two chapters to determine how well the US military is poised to maximize the use of commercial remote sensing and data-satellite constellations. This chapter also includes a detailed breakdown of each of the issues identified in the preceding two chapters, along with analysis of their significance. The examination of the remote sensing and commercial satellite communications cases suggests that the US military has substantial obstacles to the adoption of small satellite constellations. Among the obstacles that will slow adoption are substantial investments in existing military space architecture, long-term contractual commitments with legacy commercial providers, and an inefficient acquisition structure. The research concludes with recommendations and predictions for the future success of military leveraging of these emerging capabilities.

Chapter 2
Small Satellite Constellations

> *Changes in funding, or a major contribution by disruptive technologies such as small satellites, would have much more impact than changes in U.S. Government policy, law and regulation because thus far the Government itself is the business case for this commercial activity.*
> -2011 Report to the Department of Commerce on Commercial Remote Sensing

In 1997 Iridium Corporation launched the first member of its constellation of 66 communications satellites. This marked the first commercial Low Earth Orbit (LEO) satellite constellation. Iridium's constellation of satellites, weighing more than1,500 lbs each, was complete in 2002, and the company went bankrupt during the process. Iridium's failure served as a cautionary tale for the industry and was considered one of the biggest tech failures of the decade, with the company spending $5 billion before going bankrupt.[1] Only recently have serious investors started looking at launching satellite constellations once again. Interest in increasing rapidly, and there are a large number of serious efforts that promise to deliver a revolution in space. Two technologies make this revolution possible. First, the cost of space launch is decreasing dramatically for the first time. Second, the capability per pound of satellites is increasing markedly, giving rise to a new class of extremely small and very capable satellites.

In the past satellites were optimized for a specific orbit based on function. This meant that a dedicated launch platform was usually required. Because launch costs were high and a functional satellite could be built only above a certain weight, a self-reinforcing incentive cycle developed. If launch cost to orbit was going to be several hundred

[1] Douglas A. McIntyre, "The 10 Biggest Tech Failures of the Last Decade," *Time Magazine*, 14 May 2009.

million dollars, then the satellite manufacturer had an incentive to develop the most capable platform possible. As a result, satellite manufacturers built systems that were robust, capable, and designed to last on orbit for as long as possible. The desire to get as much as possible out of the investment prevented the use of extremely low orbits where atmospheric drag would limit the life of the satellite, despite the advantages to optics and low data latency that lower altitude provided. All of these factors reinforced the trend towards large, expensive satellites that today represent the overwhelming majority of satellites on orbit.

Small satellites have several advantages over traditional satellites that allow them to break the paradigm of the past. Recent developments in miniaturization of satellite components and increased understanding of the space environment allow functional platforms to be built that are significantly lighter than those of the past. Planet Labs' Dove satellites are an extreme example of this, weighing just 5 kg. These small platforms are correspondingly cheaper than their larger more robust predecessors. When combined with the ability of launch platforms to place these systems in extremely low orbits as secondary payloads using spare capacity on a launch platform, the economics of using extremely low orbits reverses. The advantages of low data latency and better optical range can be successfully exploited because these inexpensive platforms are not designed to last very long.

A short lifespan and inexpensive platform provide additional advantages to small satellites. These systems can be refreshed with new technology as it develops, and the cost of a single-satellite failure is no longer a financial and operational disaster. These factors, when combined with low launch costs per platform, encourage the development of constellations of platforms to provide an aggregate capability. Individually each small satellite in LEO is not very useful, but when combined with other small satellites in a constellation,

revolutionary communications and remote sensing capabilities are possible.

Communications Constellations

Communications platforms in extremely low orbits have the advantage of very low data-latency rates that are not possible with Geostationary platforms. In addition, LEO platforms do not require a fixed directional antenna and so can be more easily utilized on mobile platforms and in smaller form factors. These two advantages are complemented by the truly global coverage that LEO constellations provide. Geostationary satellites have limited coverage of higher and lower latitudes on the Earth due to viewing angles. Iridium has benefited from being the only commercial system capable of servicing these areas.

Iridium

Iridium is the only LEO provider currently on orbit and has been since the system first launched in 1997. At 680 kg, Iridium satellites are not small by modern standards but were revolutionary when they launched. Today these satellites are operating beyond life expectancy, and the constellation has been reduced from the necessary 66 to 64.[2] This has created interruptions in service, significantly hampering Iridium. Its next generation of satellites is already built and preparing to launch. These 66 new 860kg satellites will replace the existing constellation while providing backward compatibility with existing handsets and ground hardware.[3] Expected data rates are up to 1.4Mbps in the new constellation, and the total cost of the constellation, including launch and infrastructure upgrades, is approximately $3 billion.[4]

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[2] Rod Sladen, "Iridium Constellation Status," RodSladen.org, accessed 1 December 2016, http://www.rod.sladen.org.uk/iridium.htm.

[3] "Iridium Next Satellite Constellation, United States of America," Aerospace-technology.com, accessed 1 December 2016, *http://www.aerospace-technology.com/projects/iridium-next-satellite-constellation/*.

[4] Iridium Corporation, *Securities and Exchange Commission Form 10-k*, (McLean, VA: Iridium, 31 December 2015), 3.

Iridium represents the baseline case. Each of its emerging competitors is offering constellations at lower orbits with correspondingly lower lag times and significantly greater data rates to a larger population of users.

OneWeb

Sir Richard Branson's OneWeb will be the first of the next generation of small satellite communications networks on orbit with a planned launch date of 2019.[5] OneWeb is backed by Qualcomm and Sir Richard Branson and is expected to cost $2-3 Billion while delivering speeds of up to 50Mbps to the average user, using a constellation of 648 satellites.[6] It will produce approximately 900 satellites with several hundred held in reserve.[7] OneWeb will require a small dinner-plate-sized phased-array antenna to communicate, which can be easily mounted on mobile platforms or used to provide a base station for rebroadcasting cell-phone-like data coverage to a larger area. Spectrum bandwidth is the significant limitation for all new communications systems, and OneWeb proposes to solve this by operating in the same spectrum as Geosynchronous satellites without creating interference. The company plans on doing this by applying a technology it calls "Progressive Pitch." This technology will allow OneWeb "to unlock the spectrum in the most efficient way by gradually and slightly tilting our satellites as they approach the equator to make sure we never cause, or receive, interference."[8]

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[5] Peter B. Selding, "Virgin, Qualcomm Invest in Oneweb Satellite Internet Venture," *SpaceNews*, 15 January 2015, http://spacenews.com/virgin-qualcomm-invest-in-global-satellite-internet-plan/>.

[6] Peter B. Selding, "Virgin, Qualcomm Invest in Oneweb Satellite Internet Venture."

[7] Sebastian Anthony, "OneWeb's constellation of 700 low-altitude satellites will be built by Airbus," *Arstechnica*, 17 June 2015, https://arstechnica.com/science/2015/06/onewebs-constellation-of-700-low-altitude-satellites-will-be-built-by-airbus.

[8] OneWeb official website, accessed 29 November 2016, http://oneweb.world/

SpaceX

SpaceX has announced plans to produce a constellation of 4,425 satellites delivering speeds of up to 1Gbps per user.[9] This ambitious plan would place the satellites in an orbit of approximately 1100km with an expected lifespan of 5-7 years. These satellites would have a mass of about 385kg, making them heavier than OneWeb's. This extra mass probably accounts for the additional capability over OneWeb's offering. Like OneWeb, SpaceX will use a phased-array antenna that won't require pointing. SpaceX has not announced when this constellation will launch, but it operates on a similar model to OneWeb and will be in direct competition with it. This constellation is expected to cost approximately $10 Billion, with both Google and Fidelity investing more than $1 Billion.[10] SpaceX also has not revealed how it will deal with spectrum limitations to achieve such a high bandwidth service.

Boeing

Boeing is the most recent entrant into the small satellite constellation competition. It is also proposing a large constellation of small satellites, between 1,396 and 2,956. Like OneWeb and Space X, these satellites will operate at about 1200 km altitude.[11] Boeing plans to operate in the same spectrum (V-Band) as proposed 5G cell services, and this will require careful management by the FCC to ensure bandwidth allocation does not limit the capabilities of Boeing's proposal.[12] Boeing is a traditional satellite manufacturing company with extensive experience producing both commercial and military platforms,

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[9] Eli Blumenthal, "SpaceX looks to the skies to bring faster Internet," *USA Today,* 17 November 2016, http://www.usatoday.com/story/tech/2016/11/17/spacex-looks-skies-bring-faster-internet/94018566/>

[10] Eli Blumenthal, "SpaceX looks to the skies to bring faster Internet."

[11] Peter B. de Selding, "Boeing proposes big satellite constellations in V- and C-bands," *SpaceNews*, 23 June 2016, <*http://spacenews.com/boeing-proposes-big-satellite-constellations-in-v-and-c-bands/.*

[12] Peter B. de Selding, "Boeing proposes big satellite constellations in V- and C-bands."

so its proposal demonstrates the seriousness with which the industry is approaching this new technology.

Summary of Proposed Communications Constellations

A comparison of the various projects currently under development shows a trend towards larger, more robust constellations, capable of higher data rates than anything in existence today (see Table 1 below). OneWeb has a decisive lead over potential competition. It is the company most likely to achieve orbit first. If OneWeb successfully disrupts the space communications industry, then future constellations with more satellites, even lower data latency, and higher bandwidth will enter the market creating competition and innovation.

Table 1: Current and Projected Commercial Communications Constellations

Operator	Satellites[a]	Data Rate (per user)[b]	Mass	Launch (*projected)
OneWeb	648	50Mbps	<150kg	2019*
SpaceX	4,425	1Gbps	385kg	No Date
Boeing	1,396-2,956	?	?	No Date
Iridium	64 (66)	2.4kbps-10kbps	680kg	1997-2002
Iridium NEXT	66	128kbps-1.4Mbps	860kg	2016-2017*

[a] These numbers represent announced or reported constellation sizes. Only Iridium is on orbit
[b] Reported Data rates per user, individual platforms have differing overall capabilities
Source: Official Websites of OneWeb, Space X, Boeing, and Iridium, accessed 28 November 2016.

Remote Sensing

The US commercial remote sensing industry is dominated by a single company, DigitalGlobe, whose business is extremely dependent on the US Government and the National Geospatial Intelligence Agency (NGA) in particular. Its most recent satellite, WorldView-4, is capable of taking imagery with a resolution of .31-meters, but masses over 2400 kg

and operates at an altitude of 617 km.[13] Contrast this with Planet Labs, whose satellites operating at 420 km have a ground-sampling distance of 2.7 km while massing less than 5 kg.[14] These two systems represent extreme opposites in design philosophy. Both of these platforms are operating in sun-synchronous polar orbits, meaning that they pass over the same spot on the Earth each day at the same time as the Earth rotates in sync with their orbit. This provides advantages in imagery comparison and quality and is a favorite orbit for remote sensing platforms.

Commercial Imagery has its roots in government and military reconnaissance during the Cold War but has evolved into an extremely useful tool for the casual user. Google Earth and Google Maps made satellite imagery ubiquitous, and it has found many uses in private

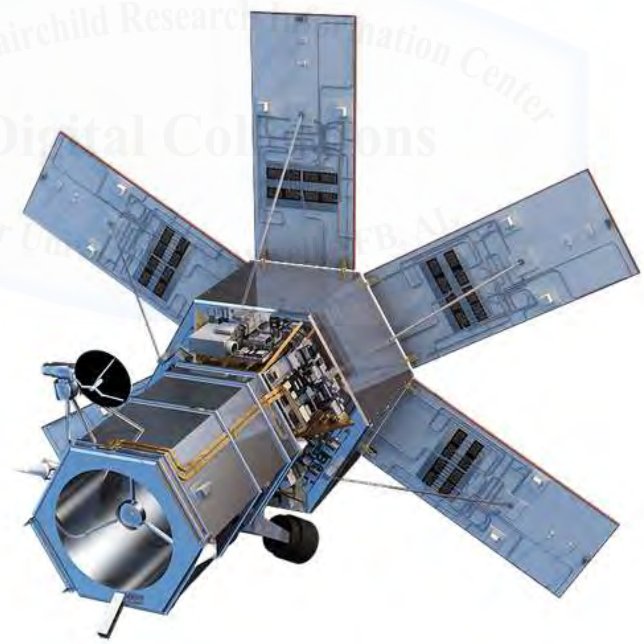

Figure 1: World View-4 the Latest Digital Globe Satellite

Source: DigitalGlobe official website, accessed 29 November 2016, http://worldview4.digitalglobe.com/#/main.

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[13] DigitalGlobe official website, accessed 29 November 2016, http://worldview4.digitalglobe.com/#/main.

[14] Planet Labs official website, accessed 1 December 2016, https://www.planet.com/docs/spec-sheets/spacecraft-ops/.

industry that have grown demand for increasingly better and more current imagery.[15] This has provided the business case for the development of inexpensive remote sensing constellations that can image all or most of the Earth as many as three times a day. A balance between quality of imagery and coverage area is where each of the competing companies are seeking a niche.

Digital Globe

Digital Globe is the one remaining US commercial imagery provider after industry consolidation. It does not operate a dedicated constellation of small satellites but serves as a baseline standard for the evolving commercial industry. Digital Globe operates five large satellites offering a resolution of between .31-meters and .5-meters.[16] These satellites mass more than 2,400kg and cost as much as $750 million each.[17] With the limited number of platforms and the high cost of the individual systems, Digital Globe's imagery is relatively expensive; and, for many users, getting access to good-enough imagery that is recent is financially out of reach. Limited access has created room for other companies to compete with Digital Globe on a cost and availability basis.

Planet Labs

Planet Labs uses a small CubeSat design which is a standardized size and inexpensive to build. Planet Labs intends to "image the Earth, every day, and to make change on our planet visible, accessible and

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[15] Bradley Hope, "Tiny Satellites: The Latest Innovation Hedge Funds Are Using to Get a Leg Up: The latest technological innovation for data-hungry hedge funds is a fleet of five dozen shoebox-sized satellites," *Wall Street Journal*, 14 August 2016.
[16] DigitalGlobe official website, accessed 29 November 2016, http://worldview4.digitalglobe.com/#/main.
[17] Peter B. de Selding, "Digital Globe Chief Sees no Competitive Threat from Earth Imagery Startups," *SpaceNews*, 21 May 2015, http://spacenews.com/digitalglobe-chief-sees-no-competitive-threat-from-earth-imagery-startups/.

actionable."[18] The company currently has approximately 60 satellites on orbit, which is short of its goal of more than 150, in order to provide imagery-refresh of the entire globe each day.[19] These satellites can be launched from the International Space Station (ISS) or as secondary payloads on traditional launch platforms and operate at orbits of between 420 km and 475 km, offering resolutions between 2.7-3.2-meters if launched from the ISS, and 3.7-4.9-meters in sun-synchronous orbits when launched as secondary payloads.[20]

Planet Labs is the first remote sensing constellation on orbit and already has government contracts. In September 2016, the National Geospatial Intelligence Agency (NGA) announced that it had concluded a seven-month introductory contract worth $20 million to utilize Planet Labs imagery.[21] This contract will provide imagery refreshed at only 15-

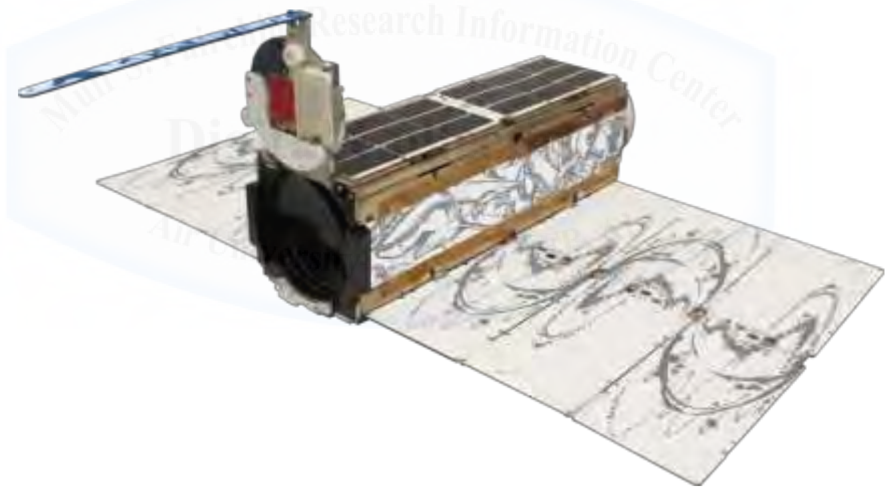

Figure 2: Dove Satellite Weighing Less Than 5kg

Source: Planet Labs official website, accessed 29 November 2016, https://www.planet.com/company/approach/

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[18] Will Marshall, "A Commitment to Sustainability." *Planet Labs*, 28 September 2015, https://www.planet.com/pulse/globalgoals/.
[19] Bradley Hope, "Tiny Satellites."
[20] Planet Labs official website, accessed 1 December 2016, https://www.planet.com/docs/spec-sheets/spacecraft-ops/.
[21] Marc Selinger. "NGA Growing in Acceptance of Satellite Imagery Startups." *Satellite Today*, 28 September 2016, http://www.satellitetoday.com/nextspace/2016/09/28/nga-growing-acceptance-satellite-imagery-startups/.

day intervals, but it demonstrates that there is a business case, both in and out of the Government, for this type of data.

TerraBella (Google/Alphabet)

TerraBella is the new name for Skybox Imaging after Google purchased it for $478 million.[22] Google's new holding company, Alphabet, purchased the company with the stated intention of providing Google Maps with up-to-date imagery and eventually moving into providing imagery for corporate customers and disaster relief.[23] The investment by Google and Alphabet represents a different niche than Planet Labs and also the most potentially disruptive satellite system in development today. TerraBella's 21, .9m resolution satellites, will provide images of most of the Earth refreshed multiple times per day.[24] The .9m resolution will allow for objects such as individual cars to be distinguishable. This resolution is often considered the threshold for truly usable imagery. These satellites also have high-resolution video capability, something that commercial systems have never fielded before.

TerraBella's satellites are significantly larger than Planet Labs' but are still much smaller than Digital Globe's. TerraBella's SkySat platforms mass less than 100kg and operate at 600km.[25] The company currently has seven satellites and will be completing its constellation of satellites in 2017. Once on orbit, TerraBella's satellites will offer operationally relevant and extremely timely imagery that represents a significant increase in capability from what is available today.

OmniEarth

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[22] Alphabet Inc., *Securities and Exchange Commission form 10K*, (Mountain View, CA: Alphabet Inc., 31 December 2015), 77.
[23] Alphabet Inc., *Securities and Exchange Commission form 10K,* pg 77
[24] Terrabella official website, accessed 1 December 2016, https://terrabella.google.com/?s=about-us&c=about-satellites.
[25] Terrabella official website, accessed 1 December 2016.

A final serious entrant into the Earth-imaging industry is OmniEarth. This company has many of the same goals as Planet Labs, with a focus on change-detection and environmental monitoring. The resolution of imagery provided by OmniEarth satellites (5 m) will be lower than Planet Labs but operate in a greater spectrum range allowing additional analytics. The stated company mission is to provide "analytics-ready, multispectral imagery from everywhere on Earth every day."[26] This imagery will have a number of uses from agriculture and water management to global-change detection. The company plans to launch a constellation of 15 satellites with hosted payload space and three on-orbit spares.

Summary of Proposed Remote Sensing Constellations

DigitalGlobe currently dominates the US market for remote sensing, but it operates on a business model that relies on exquisite high-resolution imagery that is infrequently updated. The new entrants

Table 2. Current and Projected Commercial Imaging Constellations Including Digital Globe as Reference.

Operator	Satellites[a]	Mass[b]	Highest Resolution[c]	Revisit Time[d]	Launch Year (*projected)
TerraBella (Google)	7 (21*)	<100kg	<.9m still frame, 1.1m video 30fps	<8 hours	2016-2017*
Planet Labs	60 (150*)	<5kg	2.7m - 3.7m	<24 hours	2015-2016
OmniEarth	18*	?	5m	<24 hours	2019*
DigitalGlobe	5	>2,400kg	.31m - .5m	24 hours	1999-2016

[a] Number of satellites reflects projected for TerraBella and OmniEarth
[b] Mass varies based on specific model of satellite
[c] Orbital variations and satellite capabilities reflect range of resolutions
[d] Revisit time reflects averages of constellation not necessarily specific platforms
Source: Official Websites for TerraBella at https://terrabella.google.com, Planet Labs at https://www.planet.com, OmniEarth at http://www.omniearth.net/ and Digital Globe at https://www.digitalglobe.com/, accessed 29 November 2016.

[26] "OmniEarth," Crunchbase.com accessed 1 December 2016, https://www.crunchbase.com/organization/omniearth#/entity.

into the market are looking to address a demand for frequently updated imagery that is adequate for most commercial users. To achieve this the new providers are employing emerging small satellite technology in constellations (see Table 2 above). The different entrants into this market will have to prove that they can develop a commercial market large enough to avoid relying on US Government contracts.

Summary

The development of small satellite technology, and their ability to operate in constellations to achieve effects in aggregate that far exceed the capabilities of any individual satellite, is poised to disrupt the space industry. Remote sensing and satellite communications are the two largest commercial uses of space and also where small satellites offer the most advantages over traditional platforms. When these constellations are deployed in the near future they have the potential to disrupt the existing space industry. However, the remote sensing and communications will face different challenges. The communications industry has the harder technical challenge to overcome, but once on orbit communications constellations will have a ready market and face fewer regulatory hurdles. The remote sensing industry has a more difficult path to success. It is subject to extensive regulation and has, over time, demonstrated an inability to develop a substantial market outside of the US Government.

Chapter 3
Remote Sensing

The questions that arise from the persistence of geospatial data streaming from hundreds of overhead platforms covering the earth multiple times a day are staggering. The challenges of taking advantage of all that data are daunting.
– National Geospatial Intelligence Agency Director Robert Cardillo

The Chernobyl disaster on 26 April 1986, was the catalyst that first brought home the potential impact that commercial satellite imagery could have. Images taken of the Chernobyl reactor by the satellite Landsat-5 just three days after the incident showed the extent of the damage, and suddenly the news media were able to pierce the Iron Curtain and obtain information in a way never before possible.[1] The single image taken by Landsat-5 gave the world more information about the extent of the accident than anyone had been able to piece together up to that point and was the single greatest source of evidence available to the public.[2] Information previously limited to superpowers was now available for publication and analysis by anyone with enough money. It was possible for almost anyone to purchase imagery from the US Landsat program or the newly launched French SPOT satellite. The image resolution was low by modern commercial standards, 10-meters for SPOT and 30-meters for LANDSAT, but it was good enough to make out details of major disasters and to see places and things to which the

[1] NASA GSFC Landsat/LDCM EPO Team, "Landsat Image Gallery," accessed 6 Dec 6 2016, http://landsat.visibleearth.nasa.gov/view.php?id=40535
[2] Robert P. Merges and Glenn H. Reynolds, "News Media Satellites and the First Amendment: A Case Study in the Treatment of New Technologies," *Berkeley Technology Law Journal,* Volume 3 Issue 1 (January 1988): 1.

public previously had no access (see Table 3 below for a comparison of detection resolutions).[3]

Table 3: Ground Resolution Requirements for Object Identification (meters)

Target[a]	Detection[b]	General ID[c]	Precise ID[d]	Description[e]	Technical Analysis[f]
Bridges	6	4.5	1.5	1	0.3
Communications					
Radar	3	1	0.3	0.15	0.015
Radio	3	1.5	0.3	0.15	0.015
Troop Units (in Bivouac or on Road)	6	2	1.2	0.3	0.15
Airfield Facilities	6	4.5	3	0.3	0.15
Rockets/Artillery	1	0.6	0.15	0.05	0.045
Aircraft	4.5	1.5	1	0.15	0.045
Headquaters	3	1.5	1	0.15	0.09
Surface Ships	7.5	4.5	0.6	0.3	0.045
Vehicles	1.5	0.6	0.3	0.03	0.015
Ports and Harbors	30	15	6	3	0.03
Coasts/Beaches	30	4.5	3	1.5	0.15
Rail Yards	30	15	6	1.5	0.4
Roads	6-9	6	1.8	0.6	0.4
Urban Areas	60	30	3	3	0.75
Terrain		90	4.5	1.5	0.75
Surfaced Submarines	30	6	1.5	1	0.03

[a]Chart indicates minimum resolution in meters at which a target can be detected, identified, described or analyzed.
[b]Detection location of a class of units, object, or activity of military unit
[c]General identification: determination of general target type
[d]Precise identification: discrimination within a target group
[e]Description: size/dimension, configuration, equipment count etc.
[f]Technical Analysis: detailed analysis of specific equipment
Source: James G. Lee, "Counterspace Operations for Information Dominance," in *Beyond the Paths of Heaven: The Emergence of Space Power Thought*, edited by Bruce M. Deblois (Maxwell Air Force Base, AL: Air University Press, 1999). 266.

[3] GIS Geography, "Spot Satellite Pour Observation Terre," 30 July 2016, http://gisgeography.com/spot-satellite-pour-observation-terre/.

Today satellite imagery of significantly higher quality is easily available through a number of tools and venues. It has revolutionized everything from how we see the world to how we navigate. Satellite-based observation, which began as a reconnaissance tool for the US and Soviet Governments, has progressed to a commercial tool that is increasingly necessary to the economy. It allows monitoring of commercial activity ranging from port activity to agriculture and will soon open up new markets with the development of satellite constellations offering high-quality imagery refreshed daily.

The development of a commercial remote sensing industry did not occur overnight. This chapter explores the evolving balance between national security, foreign competition, and commercial interest that has shaped the industry in ways which were not initially intended. The continuing evolution of these three factors will determine the future success of the new US commercial remote sensing ventures being proposed or already on orbit today. Two case studies are included to highlight this development. The first case study is on the evolution of the commercial remote sensing industry down to just one company and demonstrates the sensitivity of commercial industry in this area to government funding due to its inability to develop an adequate commercial market. The second case study is on efforts to develop a commercial synthetic aperture radar (SAR) satellite in the US and shows how excessive caution in licensing due to national-security concerns can adversely impact the development of a domestic market.

Remote Sensing Policy

In 1984, Congress passed the Land Remote Sensing Commercialization Act which was primarily intended to privatize the Landsat program.[4] The act was specifically targeted at developing a

[4] Land Remote-Sensing Commercialization Act of 1984, Public Law 98-365, 98th Cong., (17 July 1984), 15 USC 4201, Sec 101.

private industry to exploit the data available from Landsat. The act expressed doubt that the private sector had the ability to develop a remote sensing system "because of the high risk and large capital expenditure involved."[5] Despite this, the legislation also included a provision to allow the Secretary of Commerce to issue licenses for commercial remote sensing satellites. The Department of Commerce then delegated licensing authority to the National Oceanic and Atmospheric Administration (NOAA).[6]

The conditions for operation placed upon a company obtaining a license under the 1984 act are similar to those that exist today, with a few notable exceptions. Among those requirements that remain in effect today, a licensee is required to:

a) operate the system in such manner as to preserve and promote the national security of the United States and to observe and implement the international obligations of the United States;
b) upon termination of operations under the license, make disposition of any satellites in space in a manner satisfactory to the President;
c) furnish the Secretary with complete orbit and data collection characteristics of the system, obtain advance approval of any intended deviation from such characteristics, and inform the Secretary immediately of any unintended deviation;
d) notify the Secretary of any agreement the licensee intends to enter with a foreign nation, entity, or consortium involving foreign nations or entities;
e) furnish the Secretary with complete orbit and data collection characteristics of the system, obtain advance approval of any

[5] Land Remote-Sensing Commercialization Act of 1984, 15 USC 4201, Sec 101, 9.
[6] Dorinda Dalmeyer and Kosta Tsipis, "USAS: Civilian Uses of Near-Earth Space," *Heaven and Earth*, Vol. 16, (1997), 47.

intended deviation from such characteristics, and inform the Secretary immediately of any unintended deviation.[7]

None of the requirements listed above are particularly onerous and all exist in current law unchanged from 1984. However, several additional requirements were included in the 1984 act which made developing a commercial remote sensing platform an extremely risky investment. These included a condition allowing the Secretary of Commerce to inspect the licensee's "equipment, facilities and financial records" with no limitations.[8] The act also allowed the Secretary to "terminate, modify, condition, transfer, or suspend licenses" without any judicial recourse provided for the licensee.[9] A final aspect of the law which made private investment risky was that a system operator had the right to sell exclusive data only "for a period to be determined by the Secretary."[10] These requirements placed absolute power over commercial remote sensing in the hands of the Commerce Secretary with virtually no limitations, except for those the Secretary chose to place upon himself.

The news media led the first effort to take advantage of this new licensing arrangement. The Radio-Television News Directors Association (RTNDA) saw the obvious advantages in having access to high-quality independent satellite imagery that far exceeded what was available for purchase from the privatization of Landsat, which at the time provided only a 30-meter resolution.[11] The RTNDA concept was dubbed "mediasat" and proposed a 3-meter resolution that would have been far beyond anything then available for purchase. The major news outlets combining resources had the ability to fund the development of mediasat, but had to engage in a protracted legal battle with the US

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[7] Land Remote-Sensing Commercialization Act of 1984, 15USC 4242, Sec 402a.
[8] Land Remote-Sensing Commercialization Act of 1984, 15USC 4242, Sec 402a, 8.
[9] Land Remote-Sensing Commercialization Act of 1984, 15USC 4243, Sec 403a, 1.
[10] Land Remote-Sensing Commercialization Act of 1984, 15USC 4272, Sec 602e.
[11] Robert J. Aamoth, J. Lauerent Scharf and Enrico C. Soriano, "The Use of Remote Sensing Imagery by the News Media," *Heaven and Earth*, Vol. 16, (1997), 141.

Government to clarify the regulations. The news association believed that the vagueness of regulations "chill(ed) commercial interest in remote sensing."[12]

The RTNDA accusation that vague and arbitrary regulations were preventing investment was valid. No US commercial remote sensing platform had been launched or was in design, but the French had their SPOT-1 satellite on orbit beginning in 1986, and it offered better resolution that the US Landsat program. Regulations governing the licensing process were finally released by NOAA in 1987 in the form of 15 Consolidated Federal Regulations (CFR) Part 960.[13]

The long delay in formulating the appropriate regulations by NOAA did not result in the necessary clarification called for by the commercial market. Criticism of the regulations included their failure to define which national security obligations warranted the denial of a license and there were serious concerns that the entire set of regulations violated the First Amendment.[14] Legal literature at the time also noted the irony of denying a license for a commercial platform that could provide additional sources of data to national intelligence in order to protect national security.[15]

National Security Presidential Directive 3 (NSPD-3), signed on February 11, 1991, attempted to fix the problems with the original 1984 law.[16] NSPD-3 included a number of important changes: it listed remote sensing as one of five major commercial-space sectors; US Government agencies were directed to use commercial-space products and services to

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[12] Robert A. Weber and Kevin M. O'Connell, *Alternative Futures: United States Commercial Satellite Imagery in 2020,* Research Report for Department of Commerce and NOAA (Washington D.C.: Innovative Analytics and Training, November 2011), 14.
[13] Robert A. Weber and Kevin M. O'Connell, *Alternative Futures: United States Commercial Satellite Imagery in 2020*, 13.
[14] Robert P. Merges and Glenn H. Reynolds, "News Media Satellites and the First Amendment: A Case Study in the Treatment of New Technologies," 21.
[15] Robert P. Merges and Glenn H. Reynolds, "News Media Satellites and the First Amendment: A Case Study in the Treatment of New Technologies," 27.
[16] National Security Presidential Directive (NSPD) 3, US Commercial Space Guidelines, 11 February 1991.

the “fullest extent feasible;” and it directed that the US Government avoid regulation that deterred investment in commercial space.[17] The law also encouraged the establishment of cooperative agreements with commercial space firms. An example that included in the law was the use of “anchor tenancy.” The idea behind anchor tenancy is that the government could purchase enough of the service or product to provide the industry venture a viable initial customer base. NSPD-3 led directly to the passage of an updated law on land-remote sensing, the Land Remote Sensing Policy Act of 1992.

This legislation repealed the 1984 law and deleted the most egregious portions of it. The Act placed limitations on the Secretary of Commerce’s power to revoke a license. It required the Secretary of Commerce to obtain an injunction from Federal Court to exercise the previously unlimited powers of license termination and modification.[18] The warrantless-inspection authority of the Commerce Secretary was also now subject to the normal judicial process of obtaining subpoenas and warrants in order to conduct inspections. The law also removed the ability of the government to decide the period of exclusivity for images taken with remote sensing platforms. With the exception of a renumbering of the section as part of its inclusion in the 2010 National and Commercial Space Programs legislation, the 1992 Act remains the foundation of commercial remote sensing law.[19]

The 1992 Act finally created enough certainty in government regulation to encourage the development of a true commercial remote sensing industry. The largest US commercial-imagery provider today, DigitalGlobe and its founder, Walter Scott, identify the 1992 law as the

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[17] NSPD 3, 11 February 1991.
[18] Land Remote Sensing Act of 1992, PL 102-588, 102nd Cong., (28 October 1992), 15 USC 5623, a2.
[19] National and Commercial Space Programs, PL 111-314, 111th Cong., (18 December 2010).

beginning of the industry.[20] Scott founded his first company, named WorldView, in January of that year.[21] In 1993, WorldView received the first license under the 1992 act to operate a high-resolution commercial satellite.[22]

Motivation for the new act was not due to its predecessor's failure to promote the development of commercial remote sensing platforms, but rather the failure of the attempted privatization of the Landsat program. Under the 1984 Act, the Landsat program was managed by the Earth Observation Satellite Corporation (EOSAT) with a 10-year contract.[23] Under EOSAT management the price of data from Landsat increased sharply, which led to a corresponding decrease in demand.[24] The launch in 1986 of the government subsidized French SPOT-1 satellite, which had superior resolution, exacerbated this problem.[25] The combination of foreign competition and unsuccessful commercialization resulted in the Landsat program being returned to NASA and the Department of Defense (DOD).[26] The Department of Commerce and NOAA did retain the licensing authority granted to them in the 1984 law with the updates made to the licensing agreement mentioned above.

The next significant modification to remote sensing policy and law was Presidential Decision Directive 23 (PDD-23) signed by President Bill Clinton in 1994. This PDD had the stated intent of allowing "US firms to

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[20] Walter Scott, "U.S. Satellite Imaging Regulations Must be Modernized, Op-Ed by Digital Globe Founder," *Space News*, 29 August 2016, http://spacenews.com/op-ed-u-s-satellite-imaging-regulations-must-be-modernized/.
[21] DigitalGlobe, "Commercial Remote Sensing: A Historical Chronology," April 9, 2010. Slide 1.
[22] DigitalGlobe, "Commercial Remote Sensing: A Historical Chronology." Slide 1.
[23] Atsuyo Ito, *Legal Aspects of Satellite Remote Sensing* (Boston, MA: Marinus Nijhoff Publishers, 2011), 75.
[24] Robert J. Aamoth, J. Lauerent Scharf and Enrico C. Soriano, "The Use of Remote Sensing Imagery by the News Media," 148.
[25] Atsuyo Ito, *Legal Aspects of Satellite Remote Sensing,* 76.
[26] National Aeronautics and Space Agency (NASA), "Landsat Science: Landsat 5," NASA.gov, accessed 8 February 2017, http://landsat.gsfc.nasa.gov/landsat-5/.

compete aggressively in a growing international market."[27] The PDD recognized the increasingly competitive commercial market, which now included Russia, China, and Japan as well as France, with several other nations developing their own capabilities.[28] To accomplish its stated objective, the PDD relaxed restrictions on the export of remote sensing technology; and, following its release, the Department of Commerce approved the sale of 1-meter-resolution imagery. This was significant, as imagery resolution had been progressing rapidly, and the industry needed this authorization to be competitive in the global marketplace. The loosening of restrictions also represented a significant shift in risk calculus for the US national security community. In the late 1980's the RTNDA had lobbied for 3-meter resolution as part of mediasat, but security concerns had prevented efforts to gain approval for such a "high resolution."[29]

In combination with relaxing restrictions on imagery sale, PDD-23 introduced the concept of "shutter control." Under PDD-23, commercial-imagery providers might be required "during periods when national security…may be compromised, as defined by the Secretary of Defense or the Secretary of State, respectively, to limit data collection and/or distribution by the system to the extent necessitated by the given situation."[30] Shutter control represented a clear and substantial way that the license granted by National Oceanic and Atmospheric Administration (NOAA) could be used to protect national security. The PDD did leave it up to each of the concerned departments to develop its own internal statutory mechanisms for implementing this guidance and

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[27] Samuel L. Berger, National Security Advisor, To President of the United States, Memorandum. Subject: US policy on Foreign Access to Remote Sensing Space Capabilities, 3 March 1994.
[28] Samuel L. Berger, Memorandum 3 March 1994, 2.
[29] Robert J. Aamoth, J. Lauerent Scharf and Enrico C. Soriano, "The Use of Remote Sensing Imagery by the News Media," 141.
[30] Presidential Decision Directive 23/National Security Council, 23, US Policy on Foreign Access to Remote Sensing Space Capabilities, 9 March 1994.

placed responsibility for resolving disagreements directly on the President.

On 22 July 1998, the Secretary of Commerce announced that US commercial companies would no longer be allowed to sell high-resolution imagery of Israel.[31] Movement in this direction began the previous year with the Kyl-Bingaman amendment to the 1997 National Defense Authorization Act.[32] This amendment prevented the sale of imagery of Israel that was more detailed than imagery available from non-US sources. The enforcement of this limitation contradicted earlier assurances given by the Clinton Administration that the policy would not be enforced beyond the then 1-meter-imagery restriction, as it harmed US commercial-imagery industries' business interests in the Middle East.[33] The policy established a new precedent that the President had the power to designate any geographic area as limited by the same law. Today this specific exemption remains a part of 15 CFR 960 but has been applied only to Israel.[34]

Policy towards remote sensing satellites remained static for the remainder of the Clinton Administration. This was primarily due to the lag in the growth of the commercial market. A number of licenses were issued after the 1992 law was passed, but they had yet to result in a successful on-orbit satellite. Worldview, the company that received the first license after the 1992 law passed, had been renamed Earthwatch; and its first satellite failed on orbit in 1997 shortly after launch.[35] In 1999, the Ikonos satellite built by Lockheed Martin became the first US

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[31] Shawn L. Twing, "U.S. Bans High-Resolution Imagery of Israel," *Washington Report on Middle East Affairs*, September 1998, http://www.wrmea.org/1998-september/u.s.-bans-high-resolution-imagery-of-israel.html.

[32] National Defense Authorization Act for Fiscal Year 1997, Public Law 104-201, 104th Cong., (23 September 1996) 15 USC 5621, Sec 1064.

[33] Shawn L. Twing, "U.S. Bans High-Resolution Imagery of Israel," *Washington Report on Middle East Affairs*, September 1998, http://www.wrmea.org/1998-september/u.s.-bans-high-resolution-imagery-of-israel.html.

[34] Licensing of Private Land Remote-Sensing Space Systems; Final Rule, 15 CFR Part 960, Vol. 71, No. 79, Kyl-Bingaman Amendment (25 April 2006).

[35] DigitalGlobe, "Commercial Remote Sensing: A Historical Chronology." Slide 1.

commercially built and funded imaging satellite to achieve orbit.[36] It was quickly followed by a second and third failed attempt by Earthwatch and another attempt by a company called Orbimage, which also failed.[37] Despite these failures, by 2002 there were two US commercial remote sensing platforms on orbit that had 1-meter or better resolution capability, though US policy still prevented them from selling anything better than 1-meter imagery.

As a result of the availability of commercial imagery, in 2002 the Director of Central Intelligence issued a memorandum that created a valuable new market for the emerging industry. The memorandum made it the policy of the US "intelligence community to use US commercial space imagery to the maximum extent possible."[38] This memorandum specifically sought to stimulate the US commercial-imagery market. The imagery was not being used for intelligence purposes but primarily for mapping purposes. This memorandum led directly to the Clearview contracts issued in January 2003 to DigitalGlobe and Space Imaging. These contracts represented the first between the US government and commercial imagery providers. The Clearview contract, worth $500 million, between DigitalGlobe, Space Imaging, and the National Imagery and Mapping Agency (NIMA), provided valuable financial support and legitimacy to commercial providers, though many other agencies had yet to embrace commercial imagery.[39]

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[36] Lockheed-Martin, "Press Release: IKONOS Imaging Satellite Achieves 15 Years of On-Orbit Operation," 24 September 2014, http://www.lockheedmartin.com/us/news/press-releases/2014/september/0924-space-IKONOS.html.

[37] DigitalGlobe, "Commercial Remote Sensing: A Historical Chronology." Slide 2.

[38] George J. Tenent, Director Central Intelligence Agency, to Director, National Imagery and Mapping Agency, memorandum, Subject: Expanded Use of US Commercial Space Imagery, 7 June 2002.

[39] Frost & Sullivan, "The Billion-Dollar Promise: Clearview Contract and Greater Imagery Availability Move U.S. Satellite Commercial Imaging Market Forward," *Defense-Aerospace.com*, 21 February 2003, http://www.defense-aerospace.com/article-view/feature/18902/contract-advances-us-commercial-space-imaging.html

The Clearview contract was quickly followed by the first formal action related to remote sensing from the new presidential administration. The 2003 Commercial Remote Sensing Policy superseded PDD-23.[40] The policy reinforced the 2002 memorandum from the CIA Director and broadened it to include all government agencies. It also encouraged the development of long-term sustainable relationships between government and industry. As a result of the policy, imagery up to half-meter resolution was now authorized for sale. The first satellite capable of utilizing the new resolution limit was Worldview-1, launched in September 2007.[41] Its launch and the new regulations made US commercial providers the highest-resolution vendors available on the civilian market.

Despite the stated goals of promoting industry, the policy still sought to strike a balance between national security and commercial viability. Exports of remote sensing data and components were limited to what was already available in the global commercial marketplace.[42] Private companies did not receive the ability to determine what was available independently. PDD-23 required case-by-case review of all exports of remote sensing data and technology. Satellite components were added to the International Traffic in Arms Regulations (ITAR) in the fiscal year (FY) 1999 National Defense Authorization Act (NDAA), and the 2003 policy was not accompanied by legislative action that could change that.[43] Not until 2013 would legislative measures in the FY 2013 NDAA

[40] Whitehouse.Gov, "Press Release: US Commercial Remote Sensing Policy," 25 April 2003, https://www.whitehouse.gov/files/documents/ostp/press_release_files/fact_sheet_commercial_remote_sensing_policy_april_25_2003.pdf.
[41] DigitalGlobe, "Commercial Remote Sensing: A Historical Chronology." Slide 2.
[42] Whitehouse.Gov, "Press Release: US Commercial Remote Sensing Policy."
[43] Strom Thurmond National Defense Authorization Act for Fiscal Year 1999, Public Law 105-261, 105th Cong., (17 October 1998), 22 USC 2278, Sec 1513.

authorize the President to remove most satellite technology from ITAR to the much less restrictive Commerce Control list.[44]

Obtaining a resolution that followed the current permitted limit exactly was extremely difficult to do. Commercial companies quickly developed satellites capable of taking images at higher resolutions than they were authorized to sell. US Government agencies naturally wanted access to the best possible imagery, but national security concerns still dictated a lower resolution than was available. From this dilemma, a two-tier arrangement evolved. Under it, commercial operators were allowed to sell half-meter imagery on the commercial market, and up to .25-meter imagery to recipients individually authorized by the US Government.[45] This arrangement allowed commercial providers to develop the most capable platforms available in anticipation of a future authorization to sell still better imagery on the commercial market.

At the same time that these changes were occurring in the administration, NOAA established the Advisory Committee for Commercial Remote Sensing (ACCRES). This committee included representatives from government, academia, and industry with the purpose of providing advice to the Secretary of Commerce on issues relating to commercial remote sensing.[46] ACCRES held its firstt meeting on Sep, 30th 2002, and the board would meet a few times each year to discuss the state of the industry and provide a forum for commercial providers to make recommendations on policy changes. At its first meeting, the committee members noted the rapid growth of the industry. Since 2002, NOAA had granted 18 licenses for 41 satellites representing

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[44] National Defense Authorization Act for Fiscal Year 2013, Public Law 112-239, 112th Cong., (2 January 2013), H.R. 4310-14, Sec 1261.

[45] J. Christian Kessler, *Leadership in the Remote Sensing Satellite Industry: Report prepared for US Department of Commerce and NOAA*, (North Rave Consulting [2009]) 8.

[46] Minutes of Advisory Committee on Commercial Remote Sensing (ACCRES), 30 September 2002, https://www.nesdis.noaa.gov/CRSRA/accresMinutes.html

$2 billion in investment.[47] The establishment of ACCRES was an important development for a mature industry; previous efforts to influence remote sensing policy could be accomplished only through the lobbying of Congress.

NOAA released the current version of 15 CFR 960 governing commercial remote sensing in 2006. This version included all of the previous developments in policy and law. The Secretary of Commerce retained control of licensing with the restriction that it must process any existing license in 120 days or less. Legal restrictions on the exercise of inspections and license revocation remained as included in the 1992 act.

Imagery is currently limited to .25-meter resolution for public sale. The US Government granted this authority in 2014 in response to a request from DigitalGlobe. The founder of DigitalGlobe argued that it made the original request in 1999 and that the delay in permission was unacceptable.[48] Other sources state that the formal request from the company was made to NOAA only in 2013 and approved within a year.[49] Whatever the case, the most capable commercial platform on orbit today is Worldview-4 owned by DigitalGlobe, launched in 2016 with a resolution of .3-meters.[50]

Case Study 1: DigitalGlobe, GeoEye and the Evolution of Commercial Remote Sensing

Until 2016 the only remaining commercial provider of imagery in the US was DigitalGlobe. The director of the NGA recently referred to the

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[47] Minutes of Advisory Committee on Commercial Remote Sensing (ACCRES), 30 September 2002

[48] Walter Scott, "U.S. Satellite Imaging Regulations Must be Modernized, Op-Ed by Digital Globe Founder."

[49] Mike Gruss, "U.S. Intel Community Endorses Easing Resolution Limits on Commercial Imagery," *SpaceNews*, 15 April 2014, http://spacenews.com/40224us-intel-community-endorses-easing-resolution-limits-on-commercial/#sthash.coQQ6Ui7.dpuf.

[50] DigitalGlobe official website, accessed 29 November 2016, http://worldview4.digitalglobe.com/#/main

company as his “mission partner” that was essential to his “mapping, charting, geodesy, and intelligence missions.”[51] With five satellites offering resolutions between .31-meters and .5-meters that cost as much as $750 million and weigh more than 2,400kg each, the company does not represent a small satellite provider, but until late 2016 it represented the sole remaining commercial entity providing imagery to the US Government.[52] How DigitalGlobe became the only significant operator of commercial imagery satellites under the regulations and policies established by the government reflects the health of the industry and the dependent nature of the industry on government support. It is an illustrative example of what may happen to the emerging providers using small satellite constellations if they fail to develop a commercial market capable of supporting them without government contracts.

DigitalGlobe today represents the final merger of all remaining commercial imagery companies formed after the 1992 law was enacted. Originally incorporated as WorldView Imaging Corporation in January 1992, it anticipated the 1992 law passing later that year and received the first license to operate high-resolution imagery.[53] The company then merged with Ball Aerospace’s imagery division to become EarthWatch in September 1993.[54] As EarthWatch it launched the first fully commercial US remote sensing satellite from Russia in December 1997. This satellite, Earlybird 1, had a three-meter resolution.[55] However, the satellite failed on orbit just after launch and nearly took the company with it. A major competitor, Orbimage, was rumored to be interested in acquiring the company following the launch failure.[56] EarthWatch

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[51] Jeffrey R. Tarr, CEO DigitalGlobe, Letter to Investors, 2015 Shareowner Letter.
[52] DigitalGlobe official website, accessed 29 November 2016, https://www.digitalglobe.com/
[53] DigitalGlobe, “Commercial Remote Sensing: A Historical Chronology.” Slide 1.
[54] DigitalGlobe, *Securities and Exchange Commission Form 10-k*, (Longmont, CO: DigitalGlobe 31 December 2012), 3.
[55] DigitalGlobe, “Commercial Remote Sensing: A Historical Chronology.” Slide 1.
[56] *Space Daily*, “GoodBye Earlybird and Earthwatch Too,” *SpaceDaily*, 14 January 1998, http://www.spacedaily.com/reports/GoodBye_Earlybird__And_Earthwatch__Too.html.

persevered and built a second satellite, QuickBird 1, which was lost in a launch failure in November 2000. The company finally succeeded in launching its first satellite in October 2001 when QuickBird 2 successfully achieved orbit from Vandenberg AFB.[57] The company changed its name to DigitalGlobe the following year in August 2002.[58]

The successful launch was timely as in 2003 NIMA awarded the first contract, called Clearview, as a result of the CIA director's 2002 guidance.[59] Four separate launch failures stymied earlier efforts to obtain commercial imagery for government use in the 1990s. These efforts left just two commercial satellites on orbit. The Clearview contract awarded up to $500 million each to Digital Globe and Space Imaging over a five-year period. Space Imaging had successfully launched a .8-meter resolution satellite, named Ikonos, which made it the first commercial company to provide better than 1-meter imagery.[60] A third US commercial provider, Orbimage, was added to the contract a year later after it successfully launched its first satellite in June 2003.[61]

The Clearview contract created a vehicle for the purchasing and sharing of imagery within the government. Previously the government had to send orders for specific images to the commercial providers, but the Clearview contract vehicle changed this. Under the contract, NIMA, renamed the National Geospatial Intelligence Agency (NGA) shortly after the contract award in 2003, guaranteed a minimum revenue in the form of imagery-purchase commitments.[62] The contract also replaced a cumbersome licensing strategy for sharing the imagery purchased by the

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[57] DigitalGlobe, "Commercial Remote Sensing: A Historical Chronology." Slide 2.
[58] DigitalGlobe, *Securities and Exchange Commission Form 10-k*, 2012, 3.
[59] Frost & Sullivan, "The Billion-Dollar Promise: Clearview Contract and Greater Imagery Availability Move U.S. Satellite Commercial Imaging Market Forward."
[60] GeoImage official website, accessed 12 December 2016, http://www.geoimage.com.au/satellite/ikonos.
[61] DigitalGlobe, "Commercial Remote Sensing: A Historical Chronology." Slide 2.
[62] Orbimage, *Securities and Exchange Commission Form 10-Q,* (Washington, DC: Orbimage, 30 September 2004), 13.

NGA among other government agencies.[63] Guaranteeing a certain amount of income was a boon for the fledgling commercial companies, and in 2004 public filings, Orbimage reported that the government was its primary customer.[64]

The successor contract to Clearview, Nextview, drove the next phase of industry consolidation. The NGA selected DigitalGlobe and Orbimage under the Nextview contract, worth $1 billion, in late 2004. These contracts went beyond the simple purchasing of imagery under the Clearview contract and subsidized the construction of high-resolution satellites by both companies. In the case of Orbimage, this contract provided $237 million for the construction of OrbView-5 which the company projected to have a total cost of $502 million.[65] The third US commercial provider, Space Imaging, a joint venture between Lockheed Martin and Raytheon, was not awarded a contract under NextView. This company was founded with $750 million in capital by the two major aerospace giants and was the first to launch a commercial imaging satellite successfully, but the lack of a contract from the NGA doomed the company.[66] Orbimage purchased the company for the "fire sale" price of just $58.5 million in early 2006 and renamed itself GeoEye.[67]

By 2006 there were just two US Commercial imagery providers, DigitalGlobe and GeoEye. Despite a forecast by Merrill Lynch in 2000 that the market for commercial imagery could be as large as $2.5 billion per year by 2005, the companies in the market at that time were unable to develop enough commercial demand to support themselves outside

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[63] Dan Caterinicchia, "NIMA Seeks 'ClearView' of world," *FCW: The business of Federal Technology,* 16 January 2003, https://fcw.com/articles/2003/01/16/nima-seeks-clearview-of-world.aspx.
[64] Orbimage, *Securities and Exchange Commission Form 10-Q,* 30 September 2004, 6.
[65] Orbimage, *Securities and Exchange Commission Form 10-Q,* 30 September 2004, 7.
[66] Joseph C. Anselmo, "A New Image," *Aviation Week & Space Technology* 164, no. 5 (January 30, 2006): 55.
[67] Joseph C. Anselmo, "A New Image." 55.

government contracts.[68] That this financial prediction with a relatively short time horizon would prove so wrong was remarkable. As a result of failures and commercial costs, GeoEye had emerged as the largest provider of satellite imagery with sales of $160 million in 2005. The government grew from 49 percent of revenues for GeoEye in 2004, to 61 percent in 2005.[69,70] This further dependence on government funding would again drive the next round of industry consolidation when the demand for commercial imagery tapered off as the wars in the Middle East scaled back.

In 2008, the NGA transitioned to a Service-Level-Agreement (SLA) structure under NextView with GeoEye and DigitalGlobe that continued in future contracts. Under this SLA structure, the NGA agreed to purchase $12.5 million in imagery from GeoEye each month.[71] The SLA provided a greater amount of revenue predictability for both companies. The EnhancedView contract superseded NextView in 2010. Under this contract, both companies received a combined $7.3 billion over ten years. This included the investment in another satellite from GeoEye, GeoEye-2.[72] It was projected to cost between $750 and $800 million, of which the NGA would subsidize $337 million.[73]

The two companies did not face any domestic competition, but the French company Astrium Services, which owned the SPOT satellites, did compete for the contract. The SPOT satellites had inaugurated the

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[68] Joseph C. Anselmo, "Commercial space's sharp new image," *Aviation Week & Space Technology* 152, no. 5 (January 31, 2000): 52.
[69] Orbimage, *Securities and Exchange Commission form 10K*, (Washington, DC: Orbimage, 2004) 6.
[70] Orbimage, *Securities and Exchange Commission form 10K*, (Washington, DC: Orbimage, 2005) 8.
[71] Geoeye, *Securities and Exchange Commission form 10K*, (Dulles, VA: Geoeye, 2009) 6.
[72] Peter B. De Selding, "EnhancedView Contract Awards Carefully Structured, NGA Says" *SpaceNews*, 10 September 2010, http://spacenews.com/enhancedview-contract-awards-carefully-structured-nga-says/#sthash.7K7GA9Q4.dpuf.
[73] Geoeye, *Securities and Exchange Commission form 10K*, (Dulles, VA: Geoeye, (2010) filed 10 March 2011), 8.

commercial imaging era with the first launch in 1986.[74] Since then the company has placed a total of five satellites in orbit, all of which were subsidized by the French government. However, the French declined to support the latest generation of SPOT satellites, forcing the company to look to the US government, which remained the largest consumer of commercial imagery. Astrium's CEO, Eric Beranger, wondered publicly after the contract award if the industry as a whole was capable of surviving without government support.[75]

Under the EnhancedView contract, the government offered to co-invest in any new satellites as long as the company could file a letter of credit that demonstrated its ability to fund its portion of the cost. The letter of credit ensured the government would not be left without a final product if the company was financially unable to support its end of the bargain. GeoEye was forced to take on a new investor to obtain the required letter of credit.[76] Despite GeoEye's efforts, the government was compelled to drop this requirement as it drove up the total cost of GeoEye-2 to unacceptable levels. Instead, the NGA decided to tie funding for the satellite to milestones in GeoEye-2's construction.[77] By adopting this method, the contract looked very much like a traditional acquisition program for government satellite construction. The government was not, however, funding the entire project. GeoEye was responsible for the majority of the cost and now subject to the risk of the Government budgeting process. In effect, the NGA had shifted the entire risk for the development of the satellite to GeoEye.

[74] Updated July 30, 2016, Website Content GIS Geography http://gisgeography.com/spot-satellite-pour-observation-terre/
[75] Peter B. De Selding, "EnhancedView Contract Awards Carefully Structured, NGA Says."
[76] Peter B. De Selding, "EnhancedView Contract Awards Carefully Structured, NGA Says."
[77] Peter B. De Selding, "EnhancedView Contract Awards Carefully Structured, NGA Says."

In June 2012, the NGA informed GeoEye that it would not provide additional funds towards the development of GeoEye-2.[78] The reason cited by the NGA was that it simply did not have any additional funds to provide.[79] Despite this, in its memo to GeoEye, the NGA wished to explore the ability of the company to complete the satellite using already-obligated funds. The memorandum noted that the government continued to reserve its rights "under the Termination for Convenience Article."[80] This article under FAR 49.202a allowed the NGA to terminate the contract without providing funding for "any consequential damages" to GeoEye since the funding was limited to what was already obligated.[81] The memo was a devastating blow to GeoEye, and when combined with another memo sent the same day to GeoEye by the NGA informing it that the government would not be exercising the next SLA for imagery purchases beginning later that year "due to funding shortfalls," the company was ruined.[82]

The Senate Armed Services Committee (SASC) attempted to rescue the company by providing enough funding in the FY 13 National Defense Authorization Act (NDAA) to continue the SLA with GeoEye as well as DigitalGlobe.[83] Before the SASC could add the provision to the NDAA, DigitalGlobe and GeoEye announced plans to merge. This would leave just one US commercial-imagery provider, and Congress noted that if the

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[78] Marc M. Lessor, Contracting Officer at NGA, To GeoEye Imagery Collection Systems Inc. Memorandum, Subject: EnhancedView Other Transaction For Prototype Project (OTFPP) Agreement HM0210-10-9-0001, 22 June 2012.
[79] Marc M. Lessor, Memorandum 22 June 2012.
[80] Marc M. Lessor, Memorandum 22 June 2012
[81] Federal Acquisition Regulation part 49.202(a)
[82] Marc M. Lessor, Memorandum 22 June 2012
[83] Marcia S. Smith, "SASC Adds Funds for ORS, STP and Commercial Imagery Purchase," *Space Policy Online,* 25 May 2012, http://www.spacepolicyonline.com/news/sasc-adds-funds-for-ors-stp-and-commercial-imagery-purchase.

merger failed to obtain approval from the Justice Department, it would reconsider providing the requested funds.[84]

In a 23 July 2012 press release DigitalGlobe and GeoEye publicly announced their merger.[85] This announcement came just one month after GeoEye received notice that it would no longer be receiving funding under the EnhancedView SLA or for the construction of GeoEye-2. Neither in press releases nor other public-investor documents did the two companies cite GoeEye's loss of government funding as the impetus for the merger. Instead, they touted the efficiencies and talent-gathering aspects of the merger, with a particular focus on advantages in cost savings for the government.[86] The revenues for the combined companies for 2012 totaled more than $600 million, even after accounting for the decrease in public funds.[87]

DigitalGlobe acknowledges in their annual filings with the Securities and Exchange Commission (SEC) that their government funding is "subject to Congressional appropriations and the right of the NGA to terminate or suspend the contract at any time."[88] This creates obvious uncertainties for a company whose revenue is so dependent on government funds. In 2015, 63.7% of total revenue was from the government with the EnhancedView contract from the NGA making up 48% of that total, see Table 4 below.[89] This level has fluctuated in the

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[84] Marcia S. Smith, "House Passes Final Version of NDAA, Goes Home for Now – UPDATE," *Space Policy Online*, 21 December 2012, http://www.spacepolicyonline.com/news/house-passes-final-version-of-ndaa-goes-home-for-now-update

[85] DigitalGlobe, "DigitalGlobe and GeoEye Agree to Combine to Create a Global Leader in Earth Imagery and Geospatial Analysis," Press Release, 23 July 2012, http://investor.digitalglobe.com/phoenix.zhtml?c=70788&p=irol-newsArticle&ID=1717100

[86] DigitalGlobe, "DigitalGlobe and GeoEye Agree to Combine to Create a Global Leader in Earth Imagery and Geospatial Analysis."

[87] DigitalGlobe, "DigitalGlobe and GeoEye Agree to Combine to Create a Global Leader in Earth Imagery and Geospatial Analysis."

[88] Digital Globe, *Securities and Exchange Commission form 10K*, (Westminster, CO: Digital Globe 31 December 2015) 6.

[89] Digital Globe, *Securities and Exchange Commission form 10K,* 2015, 6.

past but remains by far the single largest source of funding for the company. Since 2012, when GeoEye and DigitalGlobe merged, the total amount of revenue generated has increased at only a moderate rate. Before 2009, the industry demonstrated substantial growth, but this leveled off when government contracts stabilized following the merger of the two companies. Non-government customers remain a small portion of the business; and, of these, the international market accounts for the largest share. In 2015, 28.9% of total revenue was from international sales, compared to 7.4% from domestic non-governmental sources.[90] That most non-governmental revenue is from international sources makes the industry extremely vulnerable to regulatory and geopolitical fluctuations.

Table 4: Percentage of Revenue for DigitalGlobe and GeoEye provided by Government and NGA 2007 to 2015

	Revenue (million USD)		All Gov. Funding (% of total)		NGA (% of total)	
Year	GeoEye	DigitalGlobe	GeoEye	DigitalGlobe	GeoEye	DigitalGlobe
2007	$183.0	$151.7	55%	68.20%	37.10%	No Data
2008	$146.6	$275.2	39%	80.80%	26%	No Data
2009	$271.1	$281.9	67%	81.90%	46%	75%
2010	$330.3	$322.5	66%	78.20%	45%	62.20%
2011	$356.4	$339.5	64%	77%	41.20%	60.10%
2012		$421.4		76.20%		60.80%
2013		$612.7		58.40%		37.10%
2014		$656.6		60.40%		38.90%
2015		$702.4		63.70%		48%

Source: Compiled by Author from Securities and Exchange Commission 10K and 10Q filings from both companies from 2007 to 2016.

With a product long associated with surveillance and intelligence, political implications can have significant impacts on the industry. DigitalGlobe's deep association with the US government has negative

[90] Digital Globe, *Securities and Exchange Commission form 10K,* 2015, 17.

consequences for sales when sensitive foreign-policy issues arise. In 2014, the company saw a $14.5 million decline in Russian business from a high of $23 million in 2013.[91,92] The company cited several potential causes for the downturn in Russian business. These included the downturn in the Russian economy due to sanctions, which did not affect DigitalGlobe's legal ability to sell imagery to Russian customers. Potentially the most significant reason cited by the DigitalGlobe CEO was the "very public use of DigitalGlobe imagery, by the U.S. government and

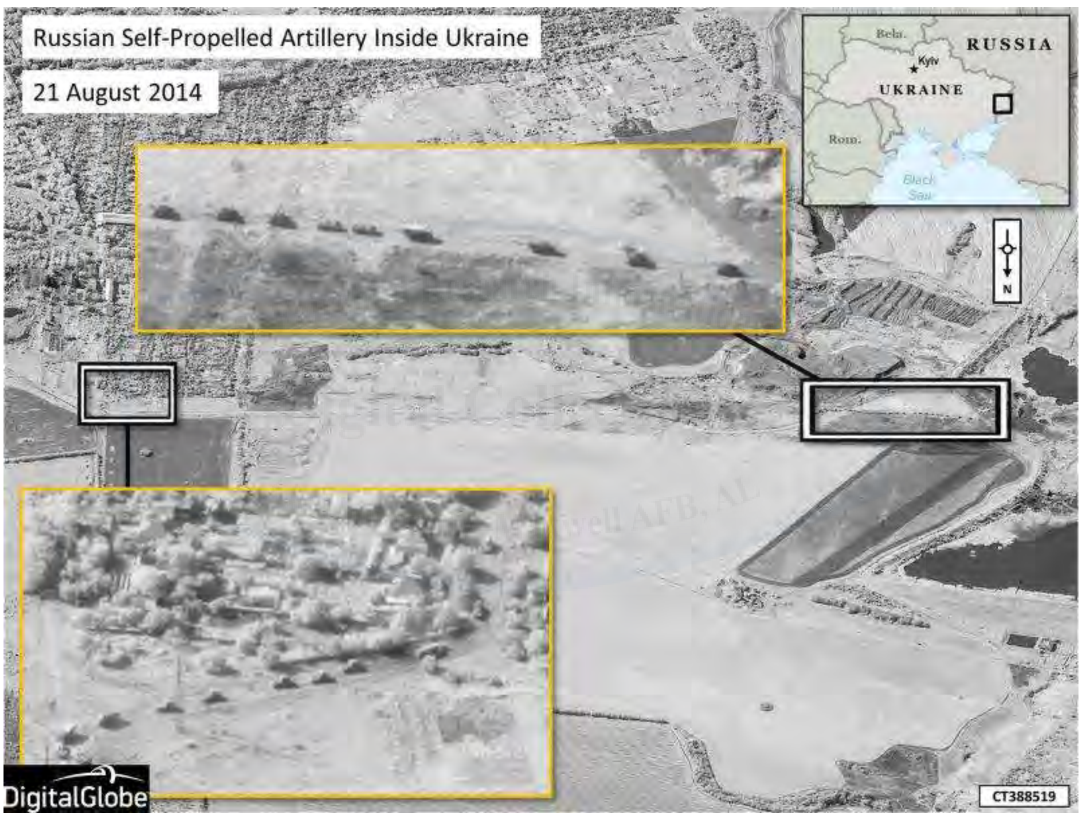

Figure 3: DigitalGlobe Image Showing Russian Military Units Within Ukraine on 21 August 2014.
Source: NATO, Supreme Headquarters Allied Powers Europe, News Release 28 August 2014, "New Satellite Imagery Exposes Russian Combat troops inside Ukraine" http://shape.nato.int/new-satellite-imagery-exposes-russian-combat-troops-inside-ukraine

[91] DigitalGlobe, Securities and Exchange Commission form 10K (Longmont, CO: DigitalGlobe, 31 December 2014) 35.
[92] Peter B. Selding, "DigitalGlobe Revenue up Despite Steep Drop in Russian Business," *SpaceNews*, 1 August 2014, http://spacenews.com/41459digitalglobe-revenue-up-despite-steep-drop-in-russian-business/.

the NATO alliance, showing Russian troop locations and, more recently, purporting to prove that missile strikes in Ukraine came from batteries located in Russian territory," (see Figure 3 above for the image referenced).[93] This assertion by the company cannot be proven, but it neatly explains the nearly complete disappearance of revenue from Russian sources following the publication of the photos by NATO. This represents a unique risk that US-based companies take when providing imagery to the military and government. An imagery company can become embroiled in larger geopolitical issues, and its non-government business jeopardized as a result.

In sum, consolidation in the commercial-imagery market to just one major supplier has been the result of two major trends. First, the commercial market proved too weak to provide the funding to support the high capital costs of building and launching a satellite using traditional launch and design methodologies. This weakness, therefore, limited the number of market players from the beginning while creating a dependence on government funding for the remaining companies. Second, the dependence on government contracts for support exposed commercial providers to the uncertainties of government budgeting and demand. The result is that each change in government funding drove industry consolidation. In 2004, when Space Imaging was not awarded a contract under NextView, it was purchased at a massive discount by GeoEye.[94] GeoEye, in turn, was forced to merge with DigitalGlobe in 2012 when the NGA abruptly cut off its funding. Changes in a single government contract were the catalysts for each of these phases of industry consolidation. Today DigitalGlobe remains dependent on the NGA contract and other government purchases to survive.

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[93] Peter B. Selding, "DigitalGlobe Revenue up Despite Steep Drop in Russian Business."
[94] Joseph C. Anselmo, "Commercial space's sharp new image." *Aviation Week & Space Technology* 152, no. 5 (January 31, 2000): 52.

Case Study 2: Development of Synthetic-Aperture Radar

Twelve separate US companies had licenses to operate remote sensing satellites by 1997, but none of those were granted for radar satellites.[95] Synthetic-Aperture Radar (SAR) remote sensing satellites have the ability to image at all hours through smoke and fog, whereas traditional electro-optical imaging satellites typically capture images between 1000 and 1400 local time to ensure the best daylight and minimize shadows. By 1997, the lack of a US commercial SAR remote sensing platform, even in the planning stages, became a concern to Congress. Then Senator Dennis DeConcini argued that "if Commerce does not license a radar satellite system, then a foreign owned radar system, with a one-meter or less capability, will enter the market leaving the U.S. government with no effective control in this area."[96] Canada had already launched Radarsat-1 in 1995 with a maximum resolution of eight-meters and had plans in place to launch a second satellite with a resolution of three-meters.[97] This case study explores how, unlike with electro-optical imaging where US commercial regulations were relatively reasonable and updated fast enough to allow for commercial growth potential, national security concerns ceded the commercial market for SAR remote sensing satellites to foreign entities, giving the US government no control over them.

Following Senator DeConcini's arguments, the DOD announced that it would oppose granting any commercial license that allowed for better than five-meter resolution imagery.[98] This restriction, when

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[95] Robert A. Weber and Kevin M. O'Connell, *Alternative Futures: United States Commercial Satellite Imagery in 2020*, 21.
[96] Robert A. Weber and Kevin M. O'Connell, *Alternative Futures: United States Commercial Satellite Imagery in 2020*, 21.
[97] Canadian Space Agency official website, accessed 26 December 2016, http://www.asc-csa.gc.ca/eng/satellites/radarsat1/default.asp.
[98] Robert A. Weber and Kevin M. O'Connell, *Alternative Futures: United States Commercial Satellite Imagery in 2020*, 33

combined with other additional restrictions, such as limits on the release of "phase history data" which allows for more accurate interpretation of spectral data, created obstacles to market entry that discouraged a successful US effort.[99] Though NOAA granted a handful of licenses over the ten years following Senator DeConcini's statements, no US company successfully produced a SAR remote sensing platform. Only under pressure from US companies to match existing foreign competition did the Department of Commerce gain approval from the interagency process to relax the resolution restrictions over time. In 2000, the requirement was dropped to three-meters, and in 2009 it was decreased further to one-meter.[100] Germany had already launched a commercial platform, TerraSar-X, with one-meter resolution in June 2007 so the US authorization was too late for US companies to establish market leadership.[101]

The consistent application of overly stringent restrictions on US companies' sale of SAR imagery effectively prevented the entry of US providers into the market until recently. In October 2015, NOAA granted a Virginia-based company, XpressSAR, a license to operate four satellites and sell X-band SAR imagery at unspecified sub-meter resolutions to private, public sector, and government customers.[102] This places a US company firmly at the leading edge of the market for the first time. However, XpressSAR does have foreign competition. UrtheCast, a Canadian company, plans to launch 16 satellites in pairs over two orbital planes. One satellite in the pair will be a SAR platform and the other an

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[99] David S. Germroth, "Commercial SAR Comes to the U.S. (Finally!)," *ApoGeo Spatial,* 9 May 2016, http://apogeospatial.com/commercial-sar-comes-to-the-u-s-finally/.
[100] Turner Brinton, "US Loosens Restrictions on Commercial Radar Satellites," *Space News*, 8 October 2009.
[101] Deutsches Zentrum für Luft- und Raumfahrt (National Aeronautics and Space Research Center) official website, Federal Republic of Germany, accessed 26 December 2016, http://www.dlr.de/dlr/en/desktopdefault.aspx/tabid-10377/565_read-436/#/gallery/350
[102] NOAA, "XpressSAR Inc. Private Remote Sensing License Public Summary," 28 October 2015, https://www.nesdis.noaa.gov/CRSRA/files/xpresssar.pdf.

optical platform with one-meter or better capability in various bands.[103] UrtheCast's constellation will allow the company to guarantee customers some form of imagery, no matter the weather conditions, every day.

Unlike in the optical-imagery realm, US regulatory restrictions ceded the SAR market to foreign companies. This prevented the United States from achieving the goals set out in various national policies to "maintain the nation's leadership in remote sensing space activities."[104] It also forced US government agencies to turn to foreign companies to obtain unclassified SAR imagery for mapping and other purposes. The NGA alone spent $85 million from 2010 to 2015 to obtain SAR imagery from Canadian, German, and Italian sources.[105] Interestingly, the NGA has no issue with this. Karyn Hayes-Ryan, the then NGA director of the commercial imagery, data, and programs group, has been quoted as saying that "we do purchase SAR [radar] imagery from several foreign sources as there is not a US source for this at present," and "we have no problem with this."[106]

The lack of US government agency support combined with national security concerns overcame US commercial desire to develop commercial SAR. The imagery market is small, and so easily saturated, and an early effort in SAR could have prevented the growth of foreign competition. Instead, the US government must pay foreign companies for access to unclassified radar imagery and has no control over what foreign customers those companies sell to. In addition, lack of presence in the market harms the US commercial satellite industry by ceding technological development and commercial growth in this field to Canada

[103] UrtheCast official website, accessed 26 December 2016, https://www.urthecast.com/constellation.

[104] National Security Presidential Directive 27, US Commercial Remote Sensing Policy, 25 April 2003.

[105] Turner Brinton, "NGA Solicits Proposals for Commercial Radar Imagery," *SpaceNews*,11 September 2009, http://spacenews.com/nga-solicits-proposals-commercial-radar-imagery/.

[106] Peter B. Selding, "EnhancedView Contrat Awards Carefully Structured, NGA Says."

and various European nations. The temporary national security gain from restrictions on the development of advanced commercial SAR systems was outweighed by the loss of control over the market. If the US controlled the SAR market, it could benefit from private investment, and through its licensing process, influence the sale and release of imagery directly. That NOAA was eventually able to grant a license to XpressSar for sub-meter-resolution imagery demonstrates that the DOD and other government agencies finally recognize that there is little to be gained from further restrictions on the US commercial SAR market.

Figure 4: Synthetic Aperture Radar Image of Ships Passing Through the Panama Canal taken by Airbus TerraSAR-X, 26 September 2013
Source: Sample Image provided by Airbus Defense & Space upon request from Author

Methods of Control

Since 1984, when the first licensing requirements were laid out, the US Government has required licensees to operate their system "in

such a manner as to preserve and promote the national security of the United States."[107] The specific controls put in place to meet this obligation are defined in 15 CFR 960. This section briefly explores the various methods of controlling remote sensing platforms and data that are available by law or have been used in the past by the US Government.

Shutter Control

The term shutter control describes the ability of the US government to restrict the operation of a satellite over a designated geographic region. PDD-23 granted this ability in combination with increasing the authorized resolution of commercial satellites to one-meter. The specific language contained in a license granted by NOAA contains the provision that: "During periods when national security or international obligations and/or foreign policies may be compromised, as defined by the Secretary of Defense or the Secretary of State respectively, the Secretary of Commerce may, after consultation with the appropriate agency(ies), require the Licensee to limit data collection and/or distribution by the system to the extent necessitated by the given situation."[108]

At the time it was created, this restriction was extremely controversial but has since never been used for two primary reasons. First, invoking the stipulation in the license would likely trigger a legal battle unless the government could demonstrate a true threat to national security. The legal challenge would probably not come from the commercial provider but rather from news agencies or other organizations seeking access to imagery. A second concern with invoking shutter control is that it could have long-term repercussions on the

[107] Land Remote-Sensing Commercialization Act of 1984, 15 USC 4242, Sec 402a.
[108] NOAA, *General Conditions for Private Remote Sensing Space System Licenses,* [2016], 1.

health of the commercial remote sensing industry. Invoking shutter control would damage the goal of fostering a healthy commercial-satellite industry by demonstrating the vulnerability of US providers to government interference.[109] Combined with the likelihood of a legal challenge, the political cost of implementing this provision has proven to be too high, even in the days following the September 11th attacks.

Buy-to-Deny

The Department of Defense (DOD) has executed a buy-to-deny form of shutter control referred to as "checkbook shutter control" just one time since the advent of commercial-imagery satellites.[110] This buy-to-deny strategy was invoked in Afghanistan during Operation Enduring Freedom in the early days of the conflict during the bombing campaign in October 2001.[111] The reported reason for this strategy was that news outlets were seeking images from the single commercial satellite available at the time with high enough resolution, Space Imaging's Ikonos, to verify reports of massive civilian casualties.[112] Attempting to invoke the legal powers granted under PDD-23 would likely have been challenged in court, so the DOD simply entered into an exclusive contract with Space Imaging for all of the imagery over Afghanistan. Exclusivity worked when there was only a single high-resolution provider available; but, as the number of commercial providers increases, the cost of executing a strategy like this will becomes prohibitive.

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[109] Congressional Research Service, *Report for Congress: Commercial Remote Sensing by Satellite: Status and Issues*, (Washington, DC: Congressional Research Service), 8 January 2002) 1.
[110] Heidner, Rick, "Shutter Control: An Approach to Regulating Imagery from Privately-operated RS Satellites." In Advisory Committee on Commercial Remote Sensing (ACCRES), Strategic Awareness and Policy Directorate. Presentation, 15 May 2014.

[111] Duncan Campbell, "US Buys up all satellite war images," *The Guardian,* 17 October 2001.
[112] Duncan Campbell, "US Buys up all satellite war images."

Diplomacy

Another option that could have more success on an international scale would be to deny access to imagery through international diplomatic channels. This option was exercised during the Gulf War when the United Nations mandated an embargo on satellite imagery sales to Iraq.[113] The only available non-US imagery was from France's SPOT satellite, and the agreement required SPOT to forgo sales to media companies in order to avoid the inadvertent release of imagery to Iraq through third parties. SPOT had a relatively low 10-meter resolution at the time but could still have provided valuable overhead intelligence to the Iraqi government, which had lost any access to aerial reconnaissance.[114] Denying access to up-to-date commercial imagery could not be a unilateral action on the part of the United States but could prove effective for short periods with support from the United Nations or as the result of carefully targeted diplomacy towards the handful of nations that host commercial satellite providers.

Denied-Parties Screening

Denied-parties screening is a control developed and maintained by the State Department where commercial imagery companies receive a list of individuals and entities to whom they cannot sell their products.[115] Since US-based remote sensing companies are subject to licensing through NOAA from the Department of Commerce, they are subject to this list. A publicly available and searchable version of this consolidated screening list is maintained online. It is designed to make it easier for companies doing business with foreign entities to ensure they are not

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113 Denette L. Sleeth, "Commercial Imagery Satellite Threat: How Can U.S. Forces Protect Themselves?" (Master's Thesis, Naval War College, 2 September 2004) 12.
114 Apollo Mapping website content accessed 26 December 2016, https://apollomapping.com/imagery/medium-resolution-satellite-imagery/spot.
115 DigitalGlobe, "Commercial Remote Sensing: A Historical Chronology." Slide 8.

under an export restriction.[116] For any company dealing with foreign entities, this list is an important tool for ensuring compliance with US law and sanctions. However, since commercial imagery products are data, they are easily shareable, and this is a poor tool for preventing the release of sensitive imagery into the public domain.

Resolution

Since the authority to regulate commercial providers was granted to it, the Commerce Department has set resolution limits on them in response to national security concerns. This is done despite there being no explicit language setting limits on resolution in any national-policy documents. Since 1992, when PDD-23 was released, and the Commerce Department authorized commercial providers to sell one-meter resolution panchromatic (black & white) imagery, the allowable panchromatic resolution has decreased first to .5-meters and then to .25-meters.[117] The current limit for multi-spectral imagery is one-meter.

The driving motivation behind lowering the authorized resolution has consistently been fear of foreign competition surpassing US capabilities. This desire to stay ahead of foreign competition has overridden national security concerns about the dangers of higher-resolution imagery in each case. With commercial providers authorized to sell .25-meter resolution imagery there seems to be little purpose to keeping limitations in place at all. It is difficult to conceive of what can be gained from further caps on resolution since the technology is now approaching physical limitations of what is possible from orbit.

In order to allow US companies to build and operate satellites with better-than-authorized capabilities for future proofing, NOAA has in the

[116] Export.Gov public website, accessed 27 December 2016, http://2016.export.gov/ecr/eg_main_023148.asp.
[117] DigitalGlobe Website official website content, accessed 23 December, 2016, http://investor.digitalglobe.com/phoenix.zhtml?c=70788&p=rsslanding&cat=news&id=1939027

past allowed operators to sell higher-than-authorized resolution imagery to the US Government under a two-tier arrangement formalized in 15 CFR 960.[118] Under this arrangement, satellite operators can sell their best-available imagery to the US government but cannot sell beyond the current limit to the public. An agreement like this was in place when the imagery limitation was one-meter. Imagery companies could sell one-meter imagery to the public and .5-meter imagery to the government. When the public limit was reduced to .5-meters, the government limit was adjusted to .25-meters. There is no current evidence that a two-tier arrangement currently exists, but this may be due to the fact that no commercial system in 2017 can image better than the authorized limit of .25-meters.

Summary

The commercial remote sensing industry is extremely dependent on government funding, regulation, and policy. Changes in any of these factors have had significant effects on the commercial remote sensing industry since it was first authorized under the 1984 Land Remote Sensing Act. Policy and regulation have proved to be consistent limiting factors in the development of a healthy remote sensing industry. These regulatory limitations are driven by a balancing act between promoting commercial competitiveness and preserving national security. Foreign competition has consistently been the factor that has driven the relaxation of restrictions. When the relaxing of restrictions is not done fast enough to allow US commercial providers to maintain a technical lead over foreign competition in the field, the market is nearly irretrievably ceded to foreign competition. US Government regulation has been relaxed fast enough for the US to maintain dominance of the optical market but not the SAR market. The industry has also

[118] Licensing of Private Land Remote-Sensing Space Systems; Final Rule, 15 CFR Part 960, Vol. 71, No. 79, 960.11 (25 April 2006).

demonstrated that it is not yet able to remain commercially viable without government support. Changes to a single contract managed by the NGA have been the cause of industry consolidation from three companies to one since 2003.

The demonstrated sensitivity to regulation and government funding does not bode well for the future development of small satellite constellations in the commercial sector, although several factors have changed. The capital cost of placing a single observation platform in orbit under the new paradigm established with small satellites is a fraction of what it cost DigitalGlobe and its predecessors. The new small satellite companies are also benefiting from decades of regulatory evolution and a small but growing commercial market fostered by DigitalGlobe. These changes may be enough to allow success for future ventures into the satellite remote sensing industry.

Chapter 4

Military use of Commercial Satellite Communications and Data

This is the President of the United States speaking. Through the marvels of scientific advance, my voice is coming to you from a satellite traveling in outer space. My message is a simple one: Through this unique means I convey to you and all mankind, America's wish for peace on Earth and goodwill toward men everywhere.

-President Dwight D. Eisenhower, 19 December 1958

Military use of satellite communications is categorized into two major areas, military satellite communications (MILSATCOM) and commercial satellite communications (COMSATCOM). MILSATCOM is made up of satellites built by contracted commercial companies for dedicated military use. Often these platforms include advanced security features, operate in unique frequency ranges, and are designed to interface with specific ground systems. Examples of MILSATCOM include Military Strategic and Tactical Relay (Milstar) and the Wideband Global SATCOM Satellites (WGS) which both operate in geosynchronous orbit, providing dedicated communications for US and selected allied military users. COMSATCOM platforms, like MILSATCOM, are usually located in geosynchronous orbit and operate by leasing bandwidth on transponders for a contracted length of time. Examples of COMSATCOM providers include US-based Intelsat which operates 54 geosynchronous satellites spanning the globe.[1] In contrast, WGS, which is designed to be the backbone of the US MILSATCOM constellation, currently consists of seven satellites with a planned total of ten.[2] The total number of MILSATCOM platforms is a small fraction of the commercial market

[1] Intelsat official website, accessed 28 December 2016, http://www.intelsat.com/global-network/satellites/fleet/

[2] US Air Force, *Fact Sheet, Wideband Global SATCOM Satellite, November 23, 2015*, http://www.af.mil/AboutUs/FactSheets/Display/tabid/224/Article/104512/wideband-global-satcom-satellite.aspx

which consists of hundreds of satellites operated by dozens of companies around the world.

The limited number of MILSATCOM platforms has driven the US military to frequently rely on commercial providers to make up for missing capacity in the military constellation. As recently as 2008 nearly 80% of US Government and military communications traffic was carried by commercial satellites.[3] The level of US military traffic carried on commercial platforms has varied depending on the pace of operations and the health of the MILSATCOM constellation. While the level of usage has varied, a significant amount of US military traffic is carried over COMSATCOM demonstrating that the US military cannot organically provide for all its communications needs, even during peacetime.

The launch of constellations of small satellites providing high-bandwidth data to terrestrial users represents a new paradigm in COMSATCOM. The commercial world is struggling to adjust to the idea that successful COMSATCOM can be conducted from low Earth orbit, something that has been cost-prohibitive in the past. While the commercial world struggles with the implications of this evolving technology, the US military and government still fail to manage the effective purchase and distribution of traditional COMSATCOM. How the US military has acquired and utilized this traditional COMSATCOM in the past will be valuable in determining its ability to properly leverage emerging low Earth orbit capabilities going forward.

This chapter explores the history of the relationship between COMSATCOM and the US military, and how that history is likely to impact the adoption of small satellites for military communications. The first section of this chapter will focus on the historical usage of

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[3] Greg Berlocher, “Military Continues to Influence Commercial Operators,” *Satellite Today*, 1 September 2008, <http://www.satellitetoday.com/publications/via-satellite-magazine/supplement/2008/09/01/military-continues-to-influence-commercial-operators/.

COMSATCOM by the US military to show the dependence that has developed between the two and the likelihood that this will continue. Also discussed are various efforts to address the cost concerns that growing dependence on COMSATCOM has created. Innovative contract vehicles and technology development are key to resolving these, and while the US Government is making great progress in reducing cost, significant work remains to develop responsive contract vehicles capable of integrating new technology. An overview of the faults present in past and existing contract vehicles provides the basis for recommendations in later chapters. This chapter concludes with a case study exploring the history of Iridium and its co-dependent relationship with the US military.

Brief history of US COMSATCOM and its relationship with the US Military

In 1964, the Tokyo Olympics was broadcast via Syncom III, a NASA experimental communications satellite launched in August of that year into geosynchronous orbit, to the United States and then rebroadcast from the US across the Atlantic Ocean to Europe via another NASA experimental satellite, Relay I.[4] With these broadcasts the age of global satellite-enabled communications began. Just two years before this broadcast, Congress passed the Communications Satellite Act which sought to "establish…a commercial communications satellite system, as part of an improved global communications network."[5] The goal of this act was to facilitate private enterprise in global satellite communications and promote competition in the sector. The act created the Communications Satellite Corporation (COMSAT) which was authorized to "plan, initiate, construct, own, manage, and operate itself or in

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[4] Delbert D. Smith, "The Legal Ordering of Satellite Telecommunication: Problems and Alternatives," Indiana Law Journal: Vol.44: Iss. 3, Article 1. (1969) 339-340, http://www.repository.law.indiana.edu/ilj/vol44/iss3/1

[5] Public Law 87-624 Communications Satellite Act of 1962, August 31, 1962 HR 11040 Sec 102a

conjunction with foreign governments or business entities a commercial communications satellite system."[6] It also placed a number of restrictions on COMSAT. Though foreign participation and relations by COMSAT were encouraged in the act, supervision by the President was required to ensure any foreign contacts were consistent with existing US foreign policy and interests.[7] Under the provisions of the act, the company helped create the International Telecommunications Satellite Consortium (INTELSAT) in August 1964, which successfully launched the first commercial communications satellite, Early Bird, in April 1965.[8]

Figure 5: President Kennedy Signs the Communications Satellite Act, 1 August 1962
Source: NASA official website, accessed 29 December 2016, https://www.nasa.gov/directorates/heo/scan/images/history/August1962_2.html.

Military communications in space remained separate from civilian communications satellites due to cost and development concerns. In

[6] Communications Satellite Act of 1962, Public Law 87-624, 87th Cong., (31 August 1962) HR 11040, Sec 305a
[7] Communications Satellite Act of 1962, Sec 201a, 4
[8] David J. Whalen, "Communications Satellites: Making the Global Village Possible," NASA History Division, http://history.nasa.gov/satcomhistory.html.

1962 then Secretary of Defense Robert McNamara had canceled a joint Army and Air Force program, called Advent, that aimed to develop a military communications satellite constellation. Secretary McNamara canceled the program due to ballooning costs and technical concerns and opened discussions with newly formed COMSAT to lease bandwidth from the commercial company at lower cost.[9] This was an ambitious goal. At the time COMSAT was a newly formed company which had not yet founded INTELSAT or even launched its first satellite. Negotiations failed because the DOD and COMSAT could not agree on costs or the need for dedicated military transponders aboard COMSAT's satellites. As a result of these disagreements with COMSAT, in July 1964 Secretary McNamara ended negotiations with COMSAT and opted for the development of a dedicated military satellite constellation under the directions of the Air Force called the Initial Defense Communications Satellite Program.[10]

From that point until Operation Desert Storm, military satellite communications needs were largely met by the MILSATCOM constellation developed following McNamara's 1964 decision. That the MILSATCOM constellation could do this was primarily the result of timing. The Vietnam war had ended before the US military could develop a significant dependence on satellite-communications capabilities. Peacetime usage did not stress the available bandwidth to a point that would drive the purchase of commercial bandwidth. This changed with the first Gulf War in 1991, when demand spiked and satellites carried over approximately 80 percent of communications.[11] This percentage was achieved despite demand exceeding supply in both bandwidth and

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[9] David N. Spires and Rick W. Sturdevant, "From Advent to Milstar: The U.S. Air Force and the Challenges of Military Satellite Communications," *NASA History*, http://history.nasa.gov/SP-4217/ch7.htm.
[10] David N. Spires and Rick W. Sturdevant, "From Advent to Milstar: The U.S. Air Force and the Challenges of Military Satellite Communications."
[11] Air Force Space Command, *Desert Storm Hot Wash "AFSPACECOM Desert Shield/Desert Storm Lessons Learned,"* (12-13 Jul 1991), 3.

satellite-capable ground equipment. Air Force Space Command (AFSPACECOM), in a review of lessons learned from the conflict, identified that communications plans had underestimated the level of demand and recommended that it acquire more satellites to support future operations.[12] Nowhere in the lessons-learned document was using COMSATCOM as a backup mentioned as an alternative, despite extensive usage during Desert Storm.

Commercial SATCOM played a substantial role in the communications architecture of the Gulf War. Just prior to the start of the conflict the total bandwidth usage in the Central Command (CENTCOM) area of operations was 4.54 Mbps.[13] This was entirely provided by MILSATCOM. Within the first month there was no longer any available MILSATCOM bandwidth, and the DOD was forced to transfer satellites from other global locations and adopt other extreme measures to support the growth of demand. At the height of the conflict, demand had increased to 67.65 Mbps carried over MILSATCOM and 31.39 Mbps carried over COMSATCOM for a total of 99.04 Mbps.[14] COMSATCOM, provided entirely by INTELSAT, was carrying 31.6 percent of all military satellite traffic and nearly 20 percent of all traffic in the entire theater. Interestingly, the military had returned to COMSAT-founded INTELSAT to carry the majority of data that traveled back to the continental United States because INTELSAT possessed both the constellation of satellites and the ground-transfer stations to support the effort, whereas the military did not.

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[12] Air Force Space Command, *Desert Storm Hot Wash,* 1,8.
[13] E Bedrosian, E.Cesar, J.Clark, G. Huth, K. Poehlmann, P. Propper*, Rand Study "Tactical Satellite Orbital Simulation and Requirements Study" report N-3568-A 1993*, (Santa Monica, CA: Rand Corp), 9.
[14] E Bedrosian, *Rand Study "Tactical Satellite Orbital Simulation and Requirements Study,"* 9-10.

Desert Storm is a benchmark for SATCOM usage.[15] During the operation SATCOM usage was 140 bps per deployed soldier. Future conflicts would see even further growth. In Kosovo in 1999 usage had increased to 3,000 bps per soldier. This growth did not stop but reached 8,300 bps per soldier in the opening days of Operation Enduring Freedom in Afghanistan and a further 13,800 bps per soldier by 2004 in Operation Iraqi Freedom.[16] Total bandwidth used in 2003 during the invasion of Iraq was 3.2 Gbps compared to the 99 Mbps used for a force more than twice as large in Desert Storm.[17] This exponential growth in SATCOM usage came at a cost to the US Government and drove an evolution in how COMSATCOM was acquired.

The sudden increase in the tempo of operations and associated increasing demand for satellite bandwidth created a free-for-all in acquiring COMSATCOM bandwidth to meet the surge. After the conflict ended, the DOD addressed this by mandating that the the Defense Information Systems Agency (DISA) would manage the process for acquiring commercial bandwidth.[18] DISA managed the process in accordance with federal regulations and standards, but the process was slow and demand was immediate. Users of DOD commercial-satellite services were dissatisfied with DISA's process, claiming that it was too slow for military operations and too expensive.[19] For this reason, many users circumvented the DISA process. The Government Accounting Office (GAO) in 2003 estimated that at least 20 percent of DOD's purchased bandwidth was acquired without going through DISA.[20]

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[15] Benjamin D. Forest, "An Analysis of Military Use of Commercial Satellite Communications," (master's thesis, Naval Post-Graduate School, September 2008) 10.
[16] Greg Berlocher,, "Military Continues to Influence Commercial Operators."
[17] "Space Systems Bandwidth," Global Secuirty.org, accessed 30 December 2016, http://www.globalsecurity.org/space/systems/bandwidth.htm
[18] United States General Accounting Office, *GAO Report 04-206 Satellite Communications: Strategic Approach Needed for DOD's Procurement of Commercial Satellite Bandwidth,* (Washington, DC: GAO, December 1993), 3.
[19] GAO Report 04-206, 2.
[20] GAO Report 04-206, 2.

Subsequent analysis by a GAO report in 2015 raised this estimate to 55 percent.[21] The GAO reported that the DOD did not know exactly how much was being spent on COMSATCOM, but it was somewhere between $300 and $400 million in 2002.[22]

The bandwidth acquired by DISA in 2003 was purchased using two different contracting models. The first was the Managed Transponder Contract (MTC) which was first awarded in 1995 to a single vendor.[23] This contract was quickly replaced in 2003 with an indefinite-delivery, indefinite-quantity, multiple-award (IDIQ) contract structure, commonly referred to as the Defense Information Systems Network Satellite Transmission Services-Global (DSTS-G). DISA adopted the DSTS-G structure after complaints that the MTC contract model was inflexible, costly, and limited in breadth.[24] However, the DSTS-G structure did not speed up the process substantially enough to satisfy customers. The average time for DISA to award a task order under DSTS-G was 79 days after receiving the request, and further time was required after that for a service provider to be selected and for service to begin to the requesting customer.[25] In contracts where users acquired bandwidth directly the process could be completed in a few weeks and was significantly less expensive than what it cost to go through DISA. In an example cited by the GAO in its 2003 report, the US Army was able to acquire COMSATCOM directly from the commercial provider for $34,700 per month as compared to a price estimate from DISA of $139,000 per month.[26] DISA priced a later upgrade of a ground terminal for this same

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[21] United States General Accounting Office, *GAO-15-459 Defense Satellite Communications: DOD Needs Additional Information to Improve Procurements,* (Washington, DC: GAO, July 2015), 9.
[22] GAO Report 04-206, 3.
[23] GAO Report 04-206, 4.
[24] GAO Report 04-206, 4.
[25] GAO Report 04-206, 13.
[26] GAO Report 04-206, 15.

contract at $579,000, but the Army was able to acquire it at $240,000 by working directly with the vendor.[27]

The GAO cited a number of potential causes for this cost differential in its 2003 report. First, DISA charged requestors an 8 percent surcharge on the contract price to cover its costs incurred in conducting the work, as authorized under the Defense Working Capital Fund.[28] Second, DISA acquired bandwidth through vendors who charged a small fee, usually between 1 and 4 percent of the total contract. Also, while the DISA contract with its vendors included the "termination-for-convenience" clause typical in US Government contracts, the vendors' contracts did not. Vendor contracts reflected typical industry practice of being liable for the remaining cost of the lease upon cancellation. The result was that the vendor, and not the service provider, was the entity that the Government would cancel the contract with; and, under government contract law, the vendor was entitled to recoup reasonable costs and a fair profit.[29] Since the vendor was liable for the full cost of the lease to the service provider, these costs became a factor in the negotiated termination settlement with DISA, and from which the agency ended up bearing some portion of the costs which were in turn passed on to the service requestor. The final factor in inflated DISA prices was poor cost estimates based on old or inaccurate data.[30] Whatever the cause, a requesting user must still have money budgeted to meet the initial cost estimate, sometimes leading users to pursue alternative acquisition methods.

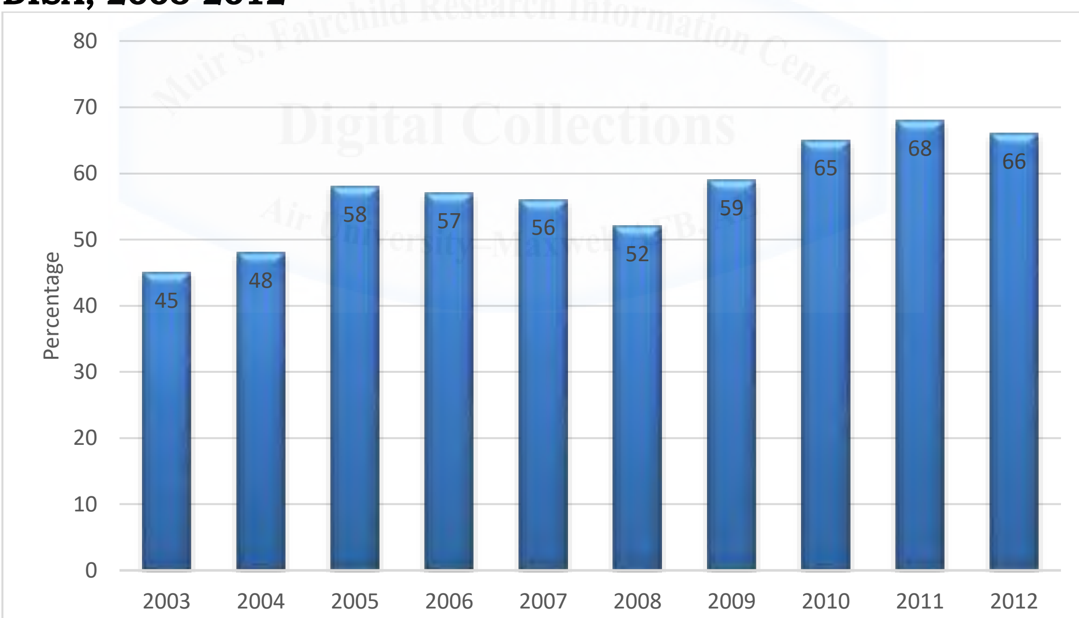
Lack of flexibility in the DSTS-G contracts occurred due to the absence of industry best practices. Under DSTS-G contracts, the user was unable to change or transfer the remaining time on the contract to a

[27] GAO Report 04-206, 15.
[28] GAO Report 04-206, 15.
[29] Federal Acquisition Regulation, *Part 49-Termination of Contracts*, 49.202 a.
[30] GAO Report 04-206, 16.

different satellite or region to meet a new need. An entirely new contract was necessary, and the old contract had to go through the termination process. The "portability of service" terms that allowed for transferring bandwidth within a service provider's constellation was an industry-standard best practice that was not being met by DSTS-G.[31]

Users were bypassing DISA within the DOD, which had no oversight on the amount of COMSATCOM users acquired. The GAO criticized the DOD in 2003 for poorly managing the entire process, from acquisition and performance metrics to enforcement of existing policies.[32] In 2015, the GAO criticized the DOD for almost exactly the same things as in 2003.[33] Users are still bypassing DISA and acquiring COMSATCOM directly, and neither the DOD nor DISA have firm control

Table 5: Percentage of DOD Fixed Satellite Services Acquired by DISA, 2003-2012



Compiled from: Source: United States General Accounting Office, *GAO-15-459 Defense Satellite Communications: DOD Needs Additional Information to Improve Procurements*, (Washington, DC: GAO, July 2015).
Source: U.S. Strategic Command. *Fiscal Year 2012 Commercial Satellite Communications Usage Report: In Response to Chairman of the Joint Chiefs of Staff Instruction 6250.01E.* 6 April 2015.

[31] GAO Report 04-206, 16.
[32] GAO Report 04-206, 19.
[33] GAO Report 15-459, 19.

over the process. The legacy of the poor process that DISA was using in 2003 exists today. Users continue to circumvent DISA and go directly to the provider to acquire bandwidth, despite GAO estimates that using DISA is now 16 percent cheaper than going directly to the vendor (see Table 5 above for DISA usage rates).[34]

The 2003 GAO report made seven key recommendations for action to DOD and DISA. These recommendations included: inventorying users; consolidating bandwidth requirements; adopting commercial practices and negotiating discounts based on volume; improving funding structure, including seeking legislative approval for multi-year funding; developing performance metrics; increasing oversight and technical analysis of requirements; and making changes to the existing acquisition process, including exploring different contract vehicles.[35] DOD "generally concur(red) with the report and its recommendations" and directed DISA to review its policies and practices.[36] However, concern remained about DOD acquisition of commercial bandwidth, and the fiscal year 2005 National Defense Authorization Act (NDAA) directed the DOD to explore alternative procurement mechanisms for COMSATCOM and provide a report on how it addressed each of the concerns in the 2003 GAO report by 30 April 2005.[37] To encourage compliance, the FY 2005 NDAA restricted the DOD from purchasing additional COMSATCOM until 30 days after Congress received the report, unless urgent national security requirements required it.[38]

The DOD submitted the report to Congress late on 29 July 2005, and the GAO review of the report determined that the DOD had fully

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[34] GAO Report 15-459, 8.
[35] GAO Report 04-206, 26-27.
[36] John P. Stenbit, Assistant Secretary of Defense for Networks and Information Integration, to Mr. William T. Woods, GAO, memorandum, subject: Department of Defense comments to the recommendations, 4 December 2003.
[37] Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005, Pub. L. No. 108-375, 108th Cong., (28 October 2004), Section 803.
[38] Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005, Section 803 d

addressed two recommendations from the 2003 report and partially addressed the others.[39] DOD fully addressed the recommendation to inventory current and potential users and rejected GAO advice to use centralized funding and multi-year procurement. The tardy nature of the report and the timing of new DOD policies on COMSATCOM, such as a December 2004 DOD policy memorandum on acquisition of COMSATCOM, imply that real action on the GAO recommendations from 2003 did not occur until mandated by law in the 2005 NDAA.[40] In addition, the recommendations that the GAO gave the DOD credit for partially fulfilling were generally promises by the DOD to conduct or begin the analysis originally recommended in 2003. What DOD accomplished was a review of several acquisition approaches with a determination that either a full and open competition model or an improved version of the DSTS-G contract were viable alternatives to the existing process, though further analysis was still required.

The GAO provided Congress with an update on DOD efforts the following year in April 2006.[41] The report concluded that DOD had made some progress but had still not developed a successor contract model. The DOD required that any successor contract would have to meet warfighter and DOD requirements, achieve cost savings, be consistent with applicable acquisition statutes, and incorporate lessons learned.[42] These steps seem obvious, but DOD had approved a list of required COMSATCOM capabilities only in February 2006.[43]

The next significant step forward in how DOD acquired COMSATCOM occurred in 2009. The director of DISA, LTG Carroll F.

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[39] United States General Accounting Office, *GAO-05-1019R DOD's Report on Commercial Communications Satellite Services Procurement Process,* (Washington, DC: GAO, 27 September 2005), 2.
[40] GAO-05-1019R, 23.
[41] United States General Accounting Office, *GAO-06-480R Status Report, Department of Defense Actions to Modify its Commercial Communications Satellite Services Procurement Process,* (Washington, DC: GAO, 17 April 2006), 1.
[42] GAO-06-480R, 5.
[43] GAO-06-480R, 5.

Pollett, and the director of the General Services Administration (GSA) signed a memorandum of agreement combining acquisition efforts and creating a common marketplace for COMSATCOM using GSA multiple-award, indefinite-delivery/indefinite-quantity (IDIQ) contract vehicles.[44] Among the reasons cited for the combining of efforts was to satisfy newly elected President Barack Obama's guidance on increased cooperation between federal agencies.[45] GSA and DISA also stated that the new effort, which would be called the Future Commercial Satellite Communications Services Acquisition (FCSA) contract model, would save the taxpayer millions of dollars by creating a common marketplace and increasing competition. The FCSA contract was designed to replace all DISA DSTS-G, GSA SATCOM II, and DOD Inmarsat contracts. The timeline given for replacing these contracts would stretch into the fourth quarter of 2011 when GSA would announce the final ID/IQ awards.[46] The FCSA contract was designed to increase competition by breaking COMSATCOM into three purchasing channels: transponded capacity, subscription services, and custom satellite solutions.[47] Unlike DSTS-G where just three vendors managed all of these services for DISA, under FCSA there were more than ten suppliers for each aspect of FCSA. FCSA effectively cut out the middleman in the contracting process allowing DISA to shop for the best provider of services.

Early excitement over the efficiencies expected to be realized under FCSA quickly faded. When the transition to FCSA occurred in 2011, the need to recompete dozens of task orders in a short window meant that

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[44] Government Services Administration, *GSA Press Release #10616, GSA and DISA Form Satellite Communications Partnership,* 6 August 2009, https://www.gsa.gov/portal/content/103695

[45] GSA Press Release #10616, GSA and DISA Form Satellite Communications Partnership

[46] Government Services Administration and Defense Information Systems Agency, *Future Commercial Satellite Communications Services Acquisition (FCSA Information sheet)*, March 2010.

[47] Nicole Grim, "Streamlined satellite acquisition advances, but challenges remain," *Defense Systems*, 14 August 2013, https://defensesystems.com/articles/2013/08/14/future-comsatcom.aspx

industry did not have time to adequately prepare bids for all the contracts and that as many as 90 percent of the task orders had only one bidder.[48] This removed one of the factors that was supposed to lead to cost savings under FCSA. The expiration of DSTS-G contracts that were secured years before during the financial crisis, when demand and prices were low, also caused sticker shock when prices under FCSA were two to three times DSTS-G prices.[49] Commercial demand was much higher in 2011 as the global economy recovered; despite DOD contracts being worth $640 million in FY2010, the industry reported satellite communications revenue of $100.3 billion for the same year with $15 billion of that total being transponder agreements and managed-satellite services.[50,51] With DOD representing just over 4 percent of the global market for fixed satellite services (FSS), competition to obtain leases and meet unique requirements from the DOD was minimal. In the first year of FCSA, the costs to the DOD of COMSATCOM spiked, and the DOD spent over $1 billion acquiring services.[52]

In 2013, the Chief Executive Officers (CEOs) and Presidents of five of the largest satellite communications companies in the world published an open letter to the DOD titled, *Seven Ways to Make the DOD a Better Buyer of Commercial SATCOM*.[53] The CEOs criticized the DOD purchasing model as inefficient and the cost-comparison methodology between MILSATCOM and COMSATCOM as deeply flawed. They pointed

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[48] Tuner Brinton, "Pentagon Seeing Sharp Price Increases for Commercial Satcom," *SpaceNews*, 18 March 2011, http://spacenews.com/pentagon-seeing-sharp-price-increases-commercial-satcom/.
[49] Tuner Brinton, "Pentagon Seeing Sharp Price Increases for Commercial Satcom."
[50] Tauri Group, *State of the Satellite Industry Report, Satellite Industry Association*, September 2015, Slide 11.
[51] Defense Business Board. *Report to the Secretary of Defense: Taking Advantage of Opportunities for Commercial Satellite Communications Services*, *Report FY13-02*, January 2013, 4.
[52] GAO-15-459, 1.
[53] Ron Samuals, Eutelsat CEO, Kay Sears, Intelsat President, Tip Osterthaler, SES CEO, Phillip Harlow, XTAR CEO and Daniel S. Goldberg, Telesat CEO, Open Letter, Subject: Seven Ways to Make the DoD a Better Buyer of Commercial SATCOM, 14 January 2013.

out that the DOD showed no ability to meet its own satellite communications needs again, and so continuing to purchase COMSATCOM using spot-market and IDIQ short-term leases resulted in much higher prices for taxpayers. Short-term leasing also created the possibility that the needed bandwidth might not be available in times of crisis due to the crowded commercial market. Instead, they recommended that DOD adopt a long-term baseline approach with a dedicated Program Objective Memorandum (POM) line for acquiring COMSATCOM. They also recommended that the DOD adopt commercial technology and standards and stop building architectures that are incompatible with commercial infrastructure. The CEOs also cited the Civil Reserve Air Fleet (CRAF) model as a way for the DOD to cover the marginal cost of building additional desired protective features into commercial satellites to increase the pool of commercial satellites with DOD-approved protective features. Finally, they proposed replacing DISA with a single office that could integrate both MILSATCOM and COMSATCOM requirements. The Air Force Space and Missile Systems Center (SMC) was their preferred integrator.

In the same month that the open letter was published, the Defense Business Board (DBB) released a report on DOD COMSATCOM that echoed many of the things proposed by the CEOs.[54] The DBB found that the DOD purchased COMSATCOM through a mixture of one-year leases (75 percent of the total) and "spot market" purchases (25 percent of the total) for which the DOD paid a premium. Commercial satellite development was also progressing significantly faster than military efforts. Commercial satellites' development timelines were 3-4 years and were substantially cheaper, while the military development timeline was 5-15 years.[55] Partnering with the COMSAT industry would allow the DOD to define requirements, leverage commercial technology, and

[54] Defense Business Board, *Report FY13-02.*
[55] Defense Business Board, *Report FY13-02,* 6.

establish a compatible architecture. They also found that military users avoided planning for COMSATCOM purchases because those costs came from the requesting users' budget, whereas MILSATCOM was perceived as free by most users due to the funding structure. Thus, COMSATCOM was purchased for the shortest interval possible and only when the need was critical, driving up costs. The DBB conducted an analysis of alternative contracting models and found obstacles to adopting each of them, see Table 6 below.

Congressional attention to the cost of COMSATCOM returned when a draft Senate version of the NDAA for FY14 included a requirement for the DOD to explore methods of long-term leasing and determine the appropriate mix of military and COMSATCOM.[56] The DOD response described their current, as of 2014, acquisition process as a "multiple-year contract with a (single) base year and price negotiated option years."[57] The report stated that this mitigated the risk of excessive cancellation charges in case of "termination for convenience" while still ensuring below-market prices. Long-term contracts, like those requested by the Senate, required stability in requirements, predictable funding, and substantial savings to the government. The DOD identified four issues related to achieving this goal that needed to be addressed:

1) accurate and timely prediction of demand
2) appropriate and stable sources of funding
3) managing capacity use to realize any apparent cost-benefit of long-term bulk leasing
4) statutory authority for multi-year contracting.[58]

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[56] Senate, *Report 113-44 – National Defense Authorization Act for Fiscal Year 2014*, 113th Congress (2013-2014).
[57] Department of Defense, *Satellite Communications Strategy Report: In Response to Senate Report 113-44 to Accompany S.1197 NDAA for FY14*, (Washington, DC: Office of the Chief Information Officer, 4 August 2014), 3.
[58] DOD, *Satellite Communications Strategy Report: In Response to Senate Report 113-44,* 4.

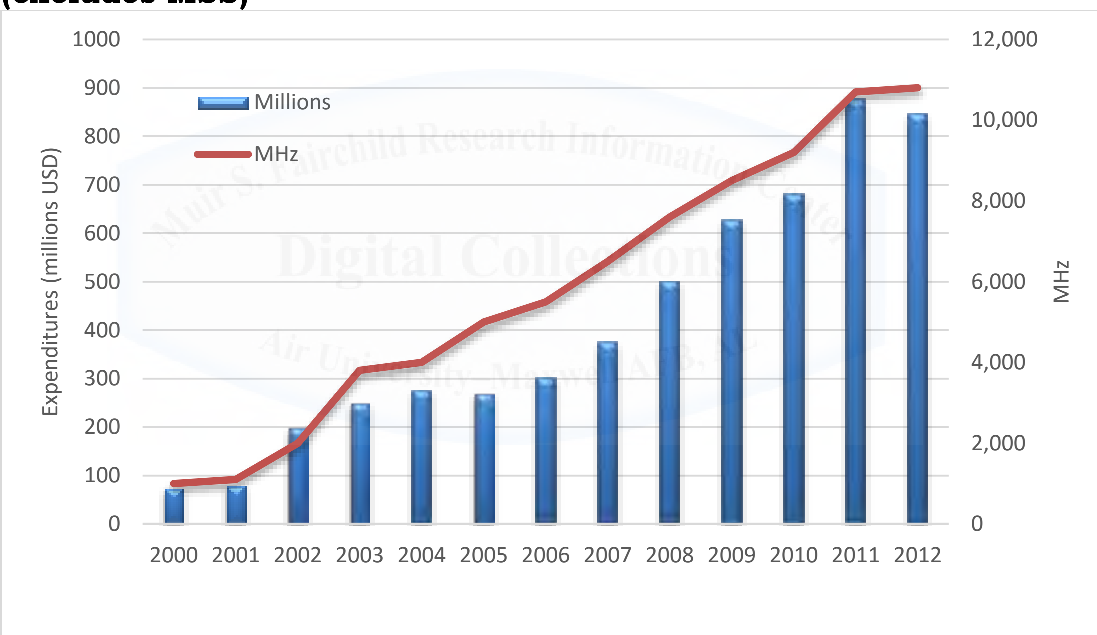
Table 6: Alternative Approaches to COMSAT Acquisition

	Alternative approaches to COMSAT acquisition	Obstacles to each approach
Buy to Lease	Make offer to a commercial operator for system use and obtain quid pro quo global service access for discount or zero charge	Funds derived from DOD asset must go to the national treasury vs. global service access deal
Capital Lease	Long term lease for satellite life (>10 years)	Programmers resist O&M dollars for investment; Procurement dollars ineligible for these deals; existing regulation limited to 5 year maximum lease
Anchor Tenancy	NASA/NOAA ability to enter into multi-year contracts to serve as the anchor tenant for commercial space ventures	Termination liability concerns; statute limited to NASA/NOAA; cannot be used for COMSAT unless authorized by Congress
Indefeasible Right of Use	Pays for up-front costs; signs agreements with others to get services and pays a large up-front fee, followed by annual charges for maintenance and upkeep	Failed providers pulling out early; poor pricing methods
Multi-year/Long term lease	Opportunity to reduce costs with longer leases	Congress uncomfortable committing dollars beyond first year; multi-year contracts limited to five years; termination liability concern
Hosted Payloads	DOD furnished payload; special needs; short timeframe	Requires prior funding; delays to timeline in acquiring new bandwidth; US launch vehicle requirement per Space Transpiration Policy
Pathfinder	Finding optimal approach to leverage COMSAT technologies, a long-term solution	Near term budget issues with the added challenge of accepting large scale non-traditional approaches; acquisition, policy, and legal concerns generate risk

Source: Adapted from Defense Business Board. *Report to the Secretary of Defense: Taking Advantage of Opportunities for Commercial Satellite Communications Services*, *Report FY13-02*. January 2013, 8.

Developing accurate demand prediction requires projecting past trends onto future events, which is a difficult and inherently inaccurate process, but something that the DOD has done when developing MILSATCOM. DOD argued that appropriate and stable funding required centralized procurement to eliminate overlap between multiple theater commanders with separate funding sources, often overseas contingency operation (OCO) funds outside the base DOD budget. The DOD would then need to increase its funding levels in the baseline budget to cover the increased cost. Managing capacity required understanding user needs, and again

Table 7: DOD Fixed Satellite Service Bandwidth Cost and Usage (excludes MSS)



Compiled from:
Source: Department of Defense. *Satellite Communications Strategy Report: In Response to Senate Report 113-44 to Accompany S.1197 NDAA for FY14*. Washington, DC: Office of the Chief Information Officer, 14 August 2014.
Source: U.S. Strategic Command. *Fiscal Year 2012 Commercial Satellite Communications Usage Report: In Response to Chairman of the Joint Chiefs of Staff Instruction 6250.01E.* 6 April 2015.
Note: Fixed satellite services (FSS) are communication services between fixed earth stations at specific locations; mobile satellite services (MSS) are communications between mobile ground based stations at varying locations by means of one or more satellites, Iridium is an example of MSS.

the DOD argued that it needed a centralized authority which it had years before dictated through internal policy but not effectively enforced. DOD concluded by pointing out that the multi-year contracting authority options recommended by the Senate were not authorized under US law for purchasing COMSATCOM.[59]

In 2015, the GAO reviewed the DOD report and overall acquisition strategy in a very similar manner to their 2003 effort. The GAO estimated that the DOD spent over $1 billion in 2011 acquiring both fixed-satellite (FSS) and mobile-satellite services (MSS) (the chart above accounts only for FSS).[60] The GAO also found that the DOD process for acquiring COMSATCOM was still highly fragmented despite DOD policy documents designating DISA as the sole procurement source. According to the GAO, the DOD estimated that at least 32 percent of its COMSATCOM leases were acquired outside of the DISA process.[61] The reasons for this fragmentation in broad terms were: the availability of Overseas Contingency Operations (OCO) funding, continued use of commercial SATCOM equipment incompatible with MILSATCOM, deployment of new weapons systems incompatible with MILSATCOM, and the ongoing increase in demand for SATCOM of all types. The GAO reiterated the need for a central funding authority with programmed funds, echoing the recommendations made in 2013 by the CEOs and Presidents of the major SATCOM companies.

In its 2014 report, the DOD identified three conditions under which commercial services were acquired: when military bandwidth was unavailable, when user demand exceeded military capability, or when user ground terminals were incompatible with MILSATCOM.[62] The

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[59] DOD, *Satellite Communications Strategy Report: In Response to Senate Report 113-44,* 7

[60] GAO-15-459, 7.

[61] GAO-15-459, 8.

[62] DOD, *Satellite Communications Strategy Report: In Response to Senate Report 113-44,* 8-9.

technology aspects of this problem were interrelated. Incompatible ground terminals were the result of the DODs resistance to adopting technology compatible with commercial standards. Therefore, when users needed SATCOM bandwidth for immediate operational purposes, they were forced to also acquire a compatible ground system at substantial cost which encourages the user to remain on commercial bandwidth, both to recoup the investment in ground hardware, and to insure against future MILSATCOM bandwidth availability limitations. This created a self-reinforcing cycle where large bandwidth users, such as UAV systems, had to rely on COMSATCOM in order to ensure availability of the SATCOM necessary to function.

The DOD strategy remained focused on maximizing the use of MILSATCOM according to the GAO.[63] This enforced reliance on MILSATCOM was due to DOD analysis demonstrating that MILSATCOM bandwidth cost $14,200 per MHz while the cost to the DOD for comparable COMSATCOM was $56,220 per MHz in 2013.[64] Numbers showing such a stark cost differential like this were contested by the CEOs of the COMSATCOM companies in their 2013 letter, where they argued that the DOD did not account for all of its costs in acquiring MILSATCOM and had an inefficient model for acquisition, which distorted the facts.[65] Using this possibly flawed cost analysis, the DOD strategy remained focused on MILSATCOM utilization while minimizing use of COMSATCOM. This strategy called for short-term contracts and spot-leasing to avoid long-term costs, which created the high costs the DOD was seeking to avoid in the first place.

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[63] DOD, *Satellite Communications Strategy Report: In Response to Senate Report 113-44*, 13.
[64] DOD, *Satellite Communications Strategy Report: In Response to Senate Report 113-44*, 8.
[65] Ron, Samuals, Eutelsat CEO, Kay Sears, Intelsat President, Tip Osterthaler, SES CEO, Phillip Harlow, XTAR CEO and Daniel S. Goldberg, Telesat CEO. Open Letter. Seven Ways to Make the DoD a Better Buyer of Commercial SATCOM. 14 January 2013.

The 2014 DOD report effectively foreclosed on the Defense Business Bureau (DBB) and Senate recommendation that it pursue long-term leases to reduce costs. The remaining avenue available to the DOD was to pursue the pathfinder strategy recommended by the DBB in its 2013 report (see Table 8).[66] The pathfinder approach called for experimentation with unique acquisition strategies on small scales to

Table 8: Summary of DISA and Air Force Pathfinder Efforts

DISA	Dates	Air Force	Dates
Requirements Analysis: Investigate and refine the Department of Defense's (DOD) understanding of global annual and long-term commercial satellite communications (SATCOM) requirements.	FY 2015-FY 2017	**Buy On-orbit Transponder:** Demonstrate investment viability and affordability in commercial bands.	FY 2014-FY 2019
Aggregated Requirements: Analyze and aggregate requirements from multiple users with similar requirements for bulk buy of commercial SATCOM services.	FY 2015-FY 2017	**Pre-launch Transponder Purchase:** Investigate the pre-launch purchase of a transponder on a commercial satellite	FY 2016-Post FY 2019
Multi-year Service Contract: Analyze multi-year contracts for long-term commercial SATCOM requirements.	FY 2015-FY 2017	**Purchase All/Part of Commercial Satellite:** Analyze the DOD purchase of all or a part of a commercial satellite, across multiple commercial constellations.	FY 2017-Post FY 2019
Utilization Monitoring: Investigate ways DOD can better manage commercial SATCOM data and spectrum usage and compare leased capacity to utilization to increase efficiency.	FY 2015-FY 2017	**Global Portable Bandwidth Trades:** Investigate the possibility of affordable, on-demand any time, place, and duration access to spare Ku band commercial transponders.	FY 2017-Post FY 2019
Active Management Pathfinder: Explore sharing commercial capability among multiple users.	FY 2015-FY 2017	**Trade for High Capacity Bits:** Examine possibility for DOD to adopt commercial high capacity satellites and managed service.	FY 2019-Post FY 2019

Source: Government Accountability Office. "Defense Satellite Communications: DOD Needs Additional Information to Improve Procurements." GAO-15-459, July 2015. Pg 16

[66] Defense Business Board, *Report FY13-02,* Pg 8.

identify potential avenues for cost saving and efficiency. The Air Force effort led by SMC would focus on long-term strategies while the DISA effort focused on shorter-term solutions to lowering cost as shown in Table 8 above.

The NDAA for FY 15 authorized the creation of these pilot programs for acquisition of COMSATCOM. [67] The FY 15 NDAA, authorized DOD to spend $50 million per FY until 2020 in order to determine the feasibility of different acquisition methods for acquiring COMSATCOM.[68] The NDAA included a requirement to investigate the use of working-capital funds and provide Congress with a report on its progress no later than December 1, 2020. Working-capital funds are typically used to finance commercial activities that provide services throughout the DOD.[69] In its 2014 report, the DOD criticized working-capital funds as "not so much acquisition strategies as they are cost accounting and cost reimbursement processes."[70] A working capital fund could assist DOD in its efforts to centralize COMSATCOM funding by providing a mechanism for centralizing and reimbursing expenditures, which could, in turn, allow for the cost savings that advocates of centralization have cited.

The Air Force placed responsibility for the Pathfinder programs with SMC. SMC developed a sequential process for accomplishing the Pathfinders. SMC first demonstrated that purchasing transponders did achieve the cost objectives by purchasing two Ku-band transponders over Africa.[71] SMC is continuing the Pathfinder process with Pathfinder 2 by purchasing transponders pre-launch from a provider and using

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[67] Carl Levin and Howard P. "Buck" Mckeon National Defense Authorization Act for FY 2015, Public Law 113-291, 113th Cong., (19 December 2014) 10 USC 2208 Sec. 1605.
[68] National Defense Authorization Act for FY 2015, 10 USC 2208 Sec. sec 1605a2
[69] DOD, *Satellite Communications Strategy Report: In Response to Senate Report 113-44,* 6
[70] DOD, *Satellite Communications Strategy Report: In Response to Senate Report 113-44,* 6
[71] Air Force Space Command, *Pathfinder 3 Request for Information: Solicitation Number 16-076*, 20 May 2016.

those purchased transponders and their equivalent bandwidth to trade for access elsewhere in the provider's constellation. SMC plans to continue experimenting with this model through three more iterations of the program. However, is has already identified several technical challenges to its model.

Moving between different commercial networks presents a similar problem to moving between MILSATCOM and COMSATCOM. Commercial providers are developing managed-network services that use proprietary waveforms and modems that limit the ability of a user to move between them. SMC identified this as a significant problem to meeting cost objectives by globally trading bandwidth between providers and various DOD customers. To address this problem, SMC released a request for information as part of Pathfinder 3 to develop a ground terminal with the ability to adapt to existing providers' needs.[72] A universal ground terminal represents a significant technical challenge and one that the DOD will also have to address with future small satellite constellations that require proprietary hardware to utilize their services.

Current Acquisition Methods

The DOD today acquires most of its COMSATCOM primarily through FCSA and its subcontracts, Custom SATCOM Solutions 2 (CS2) and CS3. The CS2 contract was valued at $3.4 billion and had a three-year base period with two one-year options. Its successor contract, CS3, which is in competition now, extends the base period out to five years with one-year options for five more years and a $2.5 billion ceiling for that extended window.[73] A successful bidder on CS3 must "provide the COMSATCOM system engineering design, configuration, installation,

[72] Air Force Space Command, *Pathfinder 3 Request for Information: Solicitation Number 16-076*, 20 May 2016.
[73] Billy Mitchell, "GSA issues $2.5 Billion satellite comms follow-on contract." *FedScoop*, 4 January 2016, http://fedscoop.com/gsa-issues-2.5b-satellite-comms-follow-on-contract.

implementation, training, and on-going maintenance and operational support necessary to deliver a COMSATCOM complex solution."[74] GSA, in its request for proposal (RFP), allowed the solution to possibly include a combination of FSS and MSS services and components. This flexibility may allow future small satellite data providers to compete successfully with a hybrid solution. However, the adoption of this future technology may be limited by the success that the GSA and DISA have had under FCSA in extending contracting authority for longer base periods.

CS2 was specifically limited to a maximum of a five-year period as a result of Pentagon and Congressional pressure. Since IDIQ contracts under FCSA do not allow for new providers during the base period, and the Pentagon did not want to miss opportunities to adopt new technology at the five-year mark, it limited CS2 to a maximum of five years.[75] The ten-year period of performance under CS3 will allow for reduced costs but will preclude the acquisition of any emerging technologies during this period. Since this time frame likely covers the initial launch and adoption of both Space X and OneWeb, the CS3 contract represents an obstacle to the adoption of new technology.

An alternative method of acquiring COMSATCOM is by using GSA's IT Schedule 70 process. This process allows for the purchase of either transponder capacity or subscription services through GSA's schedule system.[76] This schedule system is a process where the GSA negotiates IDIQ contracts with providers for services or equipment that state and federal agencies can then use to directly purchase without soliciting and evaluating competitive offers as is usually required. The GSA currently

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[74] General Services Administration, *Solicitation QTA0015SDA4003. Complex Commercial Satellite Communications (SATCOM) Solutions (CS3)*, 29 December 2015, https://www.fbo.gov/index?s=opportunity&mode=form&id=d508efff971d2325c287151dbe8e66da&tab=core&_cview=0.

[75] Sami Lais, "DISA, GSA lay out SATCOM buying Strategy," *Defense Systems*, 12 April 2010, https://defensesystems.com/articles/2010/04/08/satellite-industry-day.aspx

[76] Government Services Administration official website, accessed 16 January 2017, https://www.gsa.gov/portal/content/122627

offers the ability to purchase COMSATCOM under IT Schedule 70 on its website, but purchases under the schedule system are typically limited to $550 thousand.[77] While IT Schedule 70 "is continually open to new offers from industry partners" which would allow Space X and OneWeb access to government contracts, the monetary limit for purchases under the schedule system prevents effective broad-based adoption of new technology.[78]

Combatant Commands within the DOD with independent acquisition authority also continue to acquire COMSATCOM independent of DISA using their own funds, according to the most recent studies obtainable from the DOD.[79] The largest providers of FSS to the DOD are Eutelsat, Intelsat, and SES which provide 79.8 percent of DOD FSS COMSATCOM as of FY12.[80] Inmarsat and Iridium together account for 89 percent of the DOD mobile satellite services. These two categories together add up to an expenditure of over $1 billion, with FSS representing $846.4 million and MSS $299.2 million in FY12.[81]

The numbers cited above represent FY12 figures because they are the most recent comprehensive data available to the DOD. This demonstrates the difficulty of developing consolidated information from such a fragmented acquisition structure. Though the DOD's ability to account for total cost expenditure on COMSATCOM has improved since the 2003 GAO report, it remains a difficult exercise. DOD policy

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[77] Government Services Administration official website, accessed 16 January 2017, https://www.gsa.gov/portal/content/203021.

[78] Government Services Administration official website, accessed 16 January 2017, https://www.gsa.gov/portal/content/122627.

[79] U.S. Strategic Command, *Fiscal Year 2012 Commercial Satellite Communications Usage Report: In Response to Chairman of the Joint Chiefs of Staff Instruction 6250.01E.,* 6 April 2015.

[80] U.S. Strategic Command, *Fiscal Year 2012 Commercial Satellite Communications Usage Report* 15.

[81] U.S. Strategic Command, *Fiscal Year 2012 Commercial Satellite Communications Usage Report,* 2.

continues to designate DISA as the provider for COMSATCOM, but users continue to acquire services outside the DISA/GSA contracting process.

Case Study 3: Iridium Communications

Iridium fields the sole example of a functioning global small satellite constellation. With 66 cross-linked satellites in low-Earth orbit providing global coverage using lightweight, mobile handsets, Iridium is the baseline business model on which all future small satellite data-providers will have to improve.[82] The history of the company, its close association with the DOD and its ongoing dependence on government business, make it a suitable lens through which to predict the future relationship between the DOD and other small-satellite data-providers.

Iridium was originally conceived by Motorola Corporation in the mid-1980s when various mobile-phone technologies were competing to dominate the emerging mobile-phone market. Developed by Motorola, the Iridium constellation sought to solve early coverage issues by deploying a global-satellite constellation. The final cost of the launch and development of the system was $5 billion, and it was on orbit and available as a service in 1998.[83] The company held an opening ceremony in November of that year where Vice President Al Gore made the first phone call to inaugurate the launch of the service.[84] Despite being a marvel of technology, Iridium had only 20,000 customers by August the following year and was forced to declare bankruptcy.[85] The system relied on large heavy phones that cost $3000 each and charged between $6 and $30 dollars a minute.[86] Despite having global coverage, it failed to

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[82] Iridium official website, accessed 16 January 2017, https://www.iridium.com/network/globalnetwork
[83] Craig Mellow, "The Rise and Fall of Iridium," *Air and Space Magazine*, September 2004, http://www.airspacemag.com/space/the-rise-and-fall-and-rise-of-iridium-5615034/.
[84] S. Finkelstein and S. H. Sanford, 2000. "Learning from Corporate Mistakes: The Rise and Fall of Iridium." *Organizational Dynamics*, 29 (2):138-148, 138.
[85] S. Finkelstein and S. H. Sanford, 138.
[86] S. Finkelstein and S. H. Sanford, 138.

compete with terrestrial alternatives which focused on providing coverage in cities and other population-dense areas using smaller devices that cost substantially less to purchase and use.

Iridium defaulted on $1.5 billion in debt in August 1999 and filed for Chapter 11 bankruptcy.[87] The system was under development for 11 years, and during that time the spread of cellular technology removed the original need for the system. The significant leap in technology required to develop the Iridium constellation resulted in as many as 1,000 patent filings.[88] The technological innovation required to launch Iridium and the long lead time that satellite and system-hardware development required put Iridium at a significant disadvantage compared to terrestrial competitors. By the time Iridium launched its system, rapidly advancing cell-phone technology had rendered the Iridium handset design obsolete. Cellular coverage area had increased substantially during the 11 years that it took Iridium to develop its system, and by the time it launched in 1998 its original target audience of business users was well served in most of the major cities of the world. Iridium's failure was primarily due to the cost and time required to develop and put its system in place, which allowed terrestrial cell-phone technology to fill the original design need.

Dan Colussy, a veteran aviation industry executive, orchestrated the buyout of Iridium in 2000.[89] Putting together a consortium of four buyers, including the DOD, Colussy was able to buy out Iridium for just $25 million. This buyout offer was contingent on Motorola being indemnified against any damage from future debris that might result when the constellation de-orbited. To achieve this indemnification, Colussy leveraged the DOD. Iridium entered into an indemnification contract with the US Government in December 2000, whereby Motorola

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[87] Reuters, "Iridium Declares Bankruptcy," *New York Times*, 14 August 1999.
[88] S. Finkelstein and S. H. Sanford, 139.
[89] Craig Mellow, "The Rise and Fall of Iridium."

was not liable for future debris damage, and the new buyers were to maintain adequate insurance while subject to being ordered at any time to de-orbit the entire constellation at the US Government's discretion.[90] The de-orbiting agreement satisfied all parties, and Iridium Communications was purchased for a small fraction of its development cost in December 2000.[91]

The DOD had maintained an interest in Iridium since its inception. Of the 18 original ground stations developed for the system, one was entirely owned by the DOD. This gateway, located in Hawaii and dedicated to DOD use, was one of only two that remained open after the buyout of Iridium.[92] Colussy had also negotiated a $36-million-a-year contract with the DOD, locking in a lucrative customer with considerable leverage before the buyout was even complete.[93] Today, this gateway remains open and dedicated to US Government use. The DOD has invested substantial amounts in upgrading and maintaining this gateway since it was originally built in the late 1990s. Iridium highlights in its annual investor reports that this gateway and the significant investments the DOD made in voice and data systems to utilize it are compatible with only the Iridium satellite network.[94]

The US Government was Iridium's largest customer after its buyout and remains so today. In 2015 the US Government accounted for 23% of all Iridium revenue at $93.9 million. The DOD also has a fixed-price contract with Iridium for its services valued at $400 million with a five-year term ending in 2018.[95] This most recent contract

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[90] Iridium Communications Inc. Securities and Exchange Commission Form 10K, (Bethesda, MD: Iridium Inc., 16 March 2010), 16.
[91] Craig Mellow, "The Rise and Fall of Iridium."
[92] Craig Mellow, "The Rise and Fall of Iridium."
[93] Craig Mellow, "The Rise and Fall of Iridium."
[94] Iridium Communications Inc, *Securities and Exchange Commission Form 10K*, (McLean, VA: Iridium Communications, December 2015), 2.
[95] Iridium Communications Inc, *Securities and Exchange Commission Form 10K*, 2015, 2.

extends the US Government relationship with Iridium that has continued since its launch.

The long association with Iridium by the DOD has resulted in the development of DOD hardware dependent on the Iridium constellation. The Distributed Tactical Communications System (DTCS) is an example of this. DTCS is a system managed within DISA that provides over-the-horizon tactical and voice communications.[96] DISA advertises the system as a solution to line-of-sight communications issues that requires customers using the system to only have appropriate hardware to take advantage of it.[97] This system represents a substantial investment on the part of DOD, and will create ecosystem lock-in that will encourage resistance to the adoption of newer technologies that are currently in development.

Despite its involvement with Iridium, the DOD is not an early investor in any of the emerging small-satellite systems. The DOD's early investment in Iridium ensured the survival of the company and its technology. Since the buyout of Iridium from bankruptcy, it has been able to remain financially viable only with DOD support. This support, in the form of long-term, fixed-price contracts, has allowed Iridium the time to develop a customer base outside of the DOD. However, in the five-year period from 2010 to 2015, the DOD only decreased from 23.6 percent of Iridium's customer base to 23 percent. This minuscule change obscures the fact that total revenue increased during the same period from $76 million to $411 million.[98,99] The growth in total revenue demonstrates that there is strong demand for global satellite-

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[96] Defense Information Systems Agency, *The Distributed Tactical Communications System: Fact Sheet*, www.disa.mil/~/media/Files/DISA/Services/DTCS/DTCS-Overview.pdf

[97] Defense Information Systems Agency, *The Distributed Tactical Communications System: Fact Sheet.*

[98] Iridium Communications Inc, *Securities and Exchange Commission Form 10-k*, (McLean, VA: Iridium Communications, December 2015), 2.

[99] Iridium Communications Inc. Securities and Exchange Commission Form 10K, 16 March 2010, 1.

communications networks that can function independent of fixed ground stations.

Summary

The DOD has an ever-increasing appetite for SATCOM bandwidth. The growth of this demand far exceeds what the MILSATCOM constellation can provide. This has forced a reliance on COMSATCOM to meet a substantial percentage of total communications requirements. The short-term nature of the contracts entered into by the DOD to meet this need has resulted in high costs and inflexibility. Efforts to address these issues have made some progress in reducing costs but still suffer from an inability to centralize acquisition, long contract development timelines, and the perception of high costs relative to MILSATCOM.

Recent Congressional authorizations to explore alternatives to traditional contracting models show some signs of addressing ongoing acquisition concerns but will be only marginally applicable to developing small satellite constellations.[100] These pathfinder projects have extremely long lead times and require long-term commitments to satellite providers as well as the development of new and innovative ground hardware. The long-term contracts that have been entered into by DISA to attempt to address cost issues will also limit the ability of the DOD to adopt alternative communications infrastructure for the next ten years.

Successful DOD integration of Iridium into its communications architecture was the result of early investment in the system. The length of this investment and the development of dedicated systems to leverage this constellation will create a disincentive to adopting any other architecture. Iridium provides a template for the adoption of small satellite technology, but it also serves as a cautionary tale to the industry on the challenges of developing and marketing such a system.

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[100] DOD, *Satellite Communications Strategy Report: In Response to Senate Report 113-44,* 1.

Chapter 5

Acquisition and Policy Impacts on Small Satellite Constellation Adoption

> *"The first man-made satellite to orbit the earth was named Sputnik. The first living creature in space was Laika. The first rocket to the Moon carried a red flag. The first photograph of the far side of the Moon was made with a Soviet camera. If a man orbits the earth this year his name will be Ivan."* - U.S. Senator John F. Kennedy, in Missiles and Rockets, 10 October 1960. [1]

The preceding two chapters have extensively reviewed the policies and acquisition strategies that have shaped how the US Government and military utilize commercial SATCOM and ISR. Those chapters demonstrated that the remote sensing industry is extremely dependent on domestic policy and US Government funds. In contrast, the COMSATCOM industry, though initially founded by the US Government, has developed a healthy commercial market with its own purchasing norms and technology standards that the US Government is largely unable to influence. The only exception is the MSS portion of the industry, particularly Iridium, which has been unable to develop a large enough commercial market to remain viable without US Government support. This chapter will investigate how that history is likely to impact the future adoption of small satellite constellations in both remote sensing and COMSATCOM.

Remote Sensing

Constellations of remote sensing satellites will be unable to compete with the incumbent in satellite imagery, DigitalGlobe, regarding resolution; but they will provide marked advantages in imagery-refresh

[1] Quoted in Edward Ezell and Linda Ezell, *Competition Versus Cooperation: 1959-1962*, NASA, http://history.nasa.gov/SP-4225/documentation/competition/competition.htm.

rate and cost. The benefits these constellations provide will face a number of obstacles to their adoption and successful growth in the civilian market. These challenges include the licensing process, the dependence the industry has shown on government contracts, and the difficulty of breaking the usage paradigm that commercial imagery operates under within the US Government.

Licensing Process

Since the 1984 Land Remote Sensing Commercialization Act was passed, the legal structure to license and regulate space-based remote sensing platforms has existed in various forms. That licensing structure has been a source of continued tension with industry, as the need to balance national security concerns competed with the desire to develop a robust commercial industry. After the passage of the Land Remote Sensing Policy Act of 1992, which resolved some of the largest concerns with the 1984 law, the industry was finally able to grow, and commercial companies finally began to apply for licensing under the Act and build satellites. Despite this early growth, and the later stabilization of the industry, albeit with just one major provider, the licensing structure still possesses several flaws that make the regulation burdensome, convoluted, and unnecessary.

For much of the history of the license-security-review process, only a single factor was considered. According to former Deputy Assistant Secretary of Defense for Space Policy Douglas Loverro, the only national security concern considered when reviewing a licensing application prior to 2014 was "the harm they could do when used by an adversary."[2] Three factors are now considered when granting a license according to Mr. Loverro. These two additional factors make a significant difference in the evaluation process by expanding the strategic scope of the security

[2] Douglas Loverro (Deputy Assistant Secretary of Defense for Space Policy, Washington, DC), interview by the author, 13 January 2017.

review. The first factor added was a consideration of what additional potential benefits the launch of a system could provide to the resiliency of the US national space architecture. Resiliency is defined as "the ability of a system architecture to continue providing required capabilities in the face of system failures, environmental challenges, or adversary actions."[3] Any addition to the number of US remote sensing satellites effectively increases resiliency through redundancy, even if they are only US-licensed commercial systems. Small satellite constellations take this idea a step further and achieve resiliency through disaggregation, another term meaning "the dispersion of space-based missions, functions or sensors across multiple systems spanning one or more orbital plane, platform, host or domain."[4]

The second factor Mr. Loverro succeeded in adding was whether the technology under consideration for license was controllable by the US government. If the technology did not fall under existing export controls, or a foreign entity could easily develop it, then it was not "logical to presume you could control the development of the system going forward."[5] Adding these two additional factors to the security review rebalanced the process in favor of commercial growth and made the process more realistic in light of developing foreign capabilities. Mr. Loverro also attempted to add a fourth factor to the consideration process. This was the idea that there is a "presumption of no harm unless harm can be proven."[6] If this factor were included, the bar for granting a license to a commercial system would have been lowered, and commercial providers denied a license would have had significant legal grounds to challenge any denial.

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[3] Air Force Space Command, *Resiliency and Disaggregated Space Architectures, White Paper*, (2013), 3.
[4] Air Force Space Command, *Resiliency and Disaggregated Space Architectures*, 3.
[5] Douglas Loverro, interview 13 January 2017
[6] Douglas Loverro, interview 13 January 2017

The license-application-and-review process as it currently exists is a burden to the applicant and the government. NOAA is the agency charged by the Department of Commerce with managing the licensing and inspection process and it is quickly becoming more than NOAA can handle at its current staffing levels. This has resulted in extended timelines for licensing of remote sensing satellites. This may not be significantly harming the industry yet, but it is certainly not helping. Under regulations listed in 15 CFR 960, the Secretary of Commerce is obligated to process any license application in 120 days or less, but it currently takes significantly longer than that.[7] The number of applications has grown substantially over time. From FY 96 to FY 10, NOAA issued 26 licenses.[8] This has increased to 63 issued from FY 10 to the present, with ten applications currently being processed, and 29 more "told they must apply."[9] NOAA must also inspect the ground stations of licensees to ensure compliance with the portion of 15 CFR 960 requiring them to "protect data and information through the entire cycle of tasking operations, processing, archiving, and dissemination."[10] The compliance monitoring requirement placed the burden on NOAA of inspecting ground stations from DigitalGlobe to universities launching CubeSats. In 2016, there were 91 total ground sites around the world that needed to be inspected annually by NOAA, and as of September 2016, NOAA had inspected just 25 of the total.[11]

Along with the licensing-application process, licensees are also required to notify NOAA of "any significant or substantial agreement that they intend to enter into with any foreign nation, entity, or

[7] Minutes of Advisory Committee on Commercial Remote Sensing (ACCRES), 21 September 2016, 2.
[8] Alan Robinson, *NOAA's Commercial Remote Sensing Regulatory Affairs*, Advisory Committee on Commercial Remote Sensing (ACCRES), Update Presentation, 16 September 2016, Slide 3.
[9] Alan Robinson, *NOAA's Commercial Remote Sensing Regulatory Affairs*, 3.
[10] Licensing of Private Land Remote-Sensing Space Systems; Final Rule, 15 CFR Part 960.3.
[11] Alan Robinson, *NOAA's Commercial Remote Sensing Regulatory Affairs*, Slide 6.

consortium."[12] The agreement is then reviewed by the DOD, the Department of State, the Department of the Interior, and "any other Federal agencies determined to have a substantial interest in the foreign agreement."[13] Review through any interagency process with multiple stakeholders is not timely or easy. Once the licensing process is complete, the burden of regulation does not cease. NOAA also requires each licensee to produce a quarterly and annual report on compliance with the terms of the license agreement. All of these reports, inspections, and license approvals are managed by just a single overworked civil servant within NOAA.[14] The process for getting and maintaining a license is a burden for both the applicant and the government, with the security-review requirements achieving little in the way of added national security.

Resolution Limitations

Maintaining a resolution limit provides the US government with no significant advantages. The Commerce Department sets resolution limits on US-based commercial imagery providers in response to national security concerns. These limits have decreased from one-meter panchromatic resolution, to .5-meters, and then to .25-meters.[15] Foreign competition has been the driving motivator behind each decrease in the authorized resolution, and the current limit is set beyond the capability of any commercial platform on orbit or any that are planned. Ultimately, resolution is determined by a combination of optics and orbital altitude.

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[12] NOAA official website, accessed 28 January 2017, https://www.nesdis.noaa.gov/CRSRA/licenseHome.html.
[13] NOAA official website, accessed 28 January 2017, https://www.nesdis.noaa.gov/CRSRA/licenseHome.html
[14] Alan Robinson, NOAA Senior Licensing Officer, to the author, e-mail, 30 November 2016.
[15] DigitalGlobe Website content, accessed 23 December 2016, http://investor.digitalglobe.com/phoenix.zhtml?c=70788&p=rsslanding&cat=news&id=1939027.

Small satellites that cost significantly less than the satellites launched by DigitalGlobe trade orbital altitude and lifespan on orbit for a lower altitude to obtain better imagery with inferior optics. This tradeoff still puts the resolution of these satellites above one-meter, making the panchromatic resolution restrictions irrelevant to them at this time.

It is hard to see what is protected by limiting the resolution of commercial satellites. If national security was endangered by images with better than one-meter resolution, then what changed besides foreign competition to lower that resolution to .5-meters and again to .25-meters? At that resolution, relatively little is obscured by the current limitation (see Table 3 in Chapter 3). Mr. Loverro stated that "there were those of us who believed that no restrictions were necessary, others disagreed, so we set a limit at the (reasonable) physical limits and satisfied those who felt they had defended some turf."[16] This statement demonstrates that the limitation is not the result of objective security concerns but the result of competition among stakeholders within the US government. Those whose primary concern is the health and resiliency of the US commercial space industry supported dropping restrictions altogether, while those whose primary concern is security pushed back. The .25-meter compromise represents a point beyond which there is no current commercial need for higher-resolution imagery, and the cost of developing a commercial platform becomes prohibitive. In the words of Deputy Secretary Loverro, the US government has "created boundaries that are really no boundary at all."[17]

While the limit on panchromatic imagery is .25-meters, possibly beyond the limit of commercial interest for the foreseeable future, the limit for multispectral imagery remains one-meter.[18] Industry uses

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[16] Douglas Loverro, interview 13 January 2017
[17] Douglas Loverro, interview 13 January 2017
[18] DigitalGlobe Website content, accessed 19 April 2017, http://blog.digitalglobe.com/news/resolutionrestrictionslifted/.

multispectral imagery for everything from determining soil quality to mineral exploration; even normal color images are considered multispectral. A one-meter limitation for multispectral that is out of synch with the panchromatic imagery limit is an issue that the US Government will need to address in the near future. For now, this limit is not an issue, the most advanced commercial satellite on orbit, WorldView-4, is currently capable of only 1.24-meter multispectral imagery.[19] However, unlike for panchromatic imagery, a demand for sharper multispectral commercial imagery is likely.

Government Dependence

The remote sensing industry has demonstrated extreme dependence on US government contracts for the majority of its revenue. This dependency makes the industry vulnerable to any changes in the funding environment. From 2003, when the NGA signed its first contract with the commercial remote sensing industry, Clearview, to 2012 when funding issues under the successor contract, EnhancedView, necessitated the merger of DigitalGlobe and GeoEye, industry consolidation was entirely driven by the winners and losers of US Government funds. Table 4 in Chapter 3, where US Government funding consistently made up the bulk of revenue for DigitalGlobe and GeoEye, shows the inability of the commercial-imagery industry in the US to develop a business model not reliant on the government. As companies reliant on small satellites enter the market, they will need to demonstrate an ability to generate revenue from non-government sources in order to avoid competition for limited government funding.

The renewal of competition for limited government funding between DigitalGlobe and new entrants into the market is already occurring. In

[19] DigitalGlobe, WorldView-4 Data Sheet, accessed 19 April 2017, https://dg-cms-uploads-production.s3.amazonaws.com/uploads/document/file/196/DG_WorldView4_DS_11-15_Web.pdf.

September 2016, the NGA entered into a seven-month, $20 million contract with Planet Labs, one of the few small-satellite companies to have a substantial presence on orbit.[20] The NGA also established a joint effort with the NRO called the Commercial GEOINT Activity (CGA) the same month it entered into the contract with Planet Labs, which will "enable us to more efficiently and effectively explore alternatives to traditional collection and analysis," according to the NGA director.[21] This is a positive development for the likelihood that the US Government will successfully leverage emerging small satellite constellation capabilities, but it carries with it the risk that as these emerging companies mature they will undergo the same consolidation the traditional industry did over the last decade.

There is added danger in industry consolidation from companies relying on small satellite constellations as compared to what the traditional industry underwent for the US Government. As the traditional industry consolidated, the individual satellites that those companies controlled transferred operations to their new owner and continued being available to the government. A company that operates a satellite constellation is unlikely to be able to maintain more than one constellation profitably. Since their business models rely on cheaper platforms operating in a variety of lower orbits, the longevity of individual satellites is likely to be much less than for traditional platforms. The cost of replenishing an acquired constellation with satellites suited to that constellation will be prohibitive. If this industry consolidation occurs due to dependence on government funding, then the US

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[20] Marc Selinger, "NGA Growing in Acceptance of Satellite Imagery Startups," *Satellite Today*, 28 September 2016, <http://www.satellitetoday.com/nextspace/2016/09/28/nga-growing-acceptance-satellite-imagery-startups/.

[21] National Geospatial Intelligence Agency, "Press Release: Joint NGA/NRO activity to integrate new commercial intelligence capabilities for the Intelligence Community," 15 July 2016, https://www.nga.mil/MediaRoom/PressReleases/Pages/Joint-NGANRO-activity-to-integrate-new-commercial-geospatial-intelligence-capabilities-for-the-Intelligence-Community.aspx.

Government will bear the burden of picking winners and losers and be dependent on the advantages and disadvantages in cost, resolution, and refresh rate inherent in the design of the satellites of the remaining company. Therefore, it is in the interest of the government to do everything it can to encourage revenue diversification among these new imagery providers.

Dependence on, and close association with, the US Government can have negative repercussions on the ability of imagery providers to grow internationally. The release of commercial imagery to demonstrate culpability by an adversary to the US or its allies can have repercussions on the industry. DigitalGlobe suffered a substantial loss of business in the Russian market after the 2014 release of imagery provided to NATO showing its troops in the Ukraine. The company's imagery is also frequently used by news organizations to show Chinese island-building and military activity in the South China Sea (see Figure 6 below).[22] China and Russia are two large markets essentially closed to DigitalGlobe as the result of its association with US government and media use of its imagery in very publicly refuting their version of events. This same risk will apply to any new US-based small-satellite imagery providers that also succeed in gaining contracts with the US Government and could prove to be an even greater obstacle to their growth. Since their business models are built on providing a larger, more frequently updated database of lower quality imagery than DigitalGlobe, they are more likely to have the most recent imagery of any newsworthy event.

[22] BBC, "South China Sea: Satellite photos show weapons built on islands," *BBC News,* 15 December 2016. http://www.bbc.com/news/world-asia-38319253

Figure 6: DigitalGlobe Image Highlighting Weapons Installations on an Island in the South China Sea on 23 November 2016.
Source: BBC, "South China Sea: Satellite photos show weapons built on islands," *BBC News,* 15 December 2016. http://www.bbc.com/news/world-asia-38319253

Usage Paradigm

Breaking the paradigm that commercial imagery is only useful as "foundational" imagery will be another challenge. The NGA, in its October 2015 *Commercial GEOINT Strategy* report, stated that it would "seek opportunities to capitalize on emerging high bandwidth service to traditionally disadvantaged locations to deliver an even broader complement of foundation GEOINT and intelligence products."[23] The statement demonstrates an admirable commitment to leveraging existing and emerging commercial products, but there is a preconception in the use of the word "foundation." The NGA still sees commercial products as background data and not something that can be tactically relevant to the

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[23] National Geospatial Intelligence Agency, *Commercial GEOINT Strategy*, (Washington, DC: NGA, October 2015), 9.

warfighter if it is both 'good enough' and 'new enough.' As part of the NGA Commercial Initiative to Buy Operationally Responsive GEOINT (CIBORG), the agency recently completed a $20 Million contract to obtain global imagery from one of these new companies, Planet Labs, for products that will be updated every 15 days.[24] While this sounds impressive, at the UN sustainable-goals conference in 2015 the Planet Labs representative stated that the company goal is to "image the entire Earth, every day, and to make change on our planet visible and actionable." The company already has a web-based visual tool that allows a registered user to access and manipulate imagery refreshed daily. Even relatively low-quality imagery that is updated daily, shareable, and good enough will be an invaluable tool to military operations.

Control

Preventing potential adversaries from gaining access to commercial imagery is going to be increasingly difficult. In an effort to prevent Saddam Hussein's regime in Iraq from obtaining intelligence on the location and buildup of coalition forces in the 1991 Gulf War, the United Nations mandated an embargo on imagery sales to Iraq.[25] For this embargo to be effective it also had to apply to news organizations from which Saddam could have obtained the information second hand. Since SPOT Image was the only non-US source of commercial imagery, this embargo was effective and invaluable to the surprise achieved by US and Coalition forces as they conducted one of the largest flanking maneuvers in history, striking Iraqi defenses from the West unexpectedly. Despite the UN mandate, SPOT Image reserved the right to release imagery "if

[24] Marc Selinger, "NGA Growing in Acceptance of Satellite Imagery Startups."
[25] Denette L. Sleeth, "Commercial Imagery Satellite Threat: How Can U.S. Forces Protect Themselves?" 12.

another source provided imagery to the media."[26] More recently, the US conducted a buy-to-deny strategy in the opening days of Operation Enduring Freedom in Afghanistan in 2001 to prevent the release of sensitive images depicting the impact of bombing.[27] Despite only a single US licensed satellite being capable of providing the resolution necessary to evaluate claims of substantial civilian casualties, the DOD did not exercise its "shutter control" privileges granted under the terms of the license. Two years later, when the US again invaded Iraq, and even low-resolution images could provide valuable intelligence to Saddam Hussein's regime, the US did not attempt any form of imagery control.[28] Today, the rapid proliferation of foreign and domestic imaging platforms capable of achieving resolutions that could provide valuable intelligence to an enemy makes the possibility of an effective embargo or a buy-to-deny strategy increasingly remote.

If the US Government was unwilling to exercise the limitations granted under the licensing agreements on domestic providers when it could have created an effective embargo, then keeping the restrictions in place when it cannot makes little sense. While shutter control has never been invoked, partly because of the fear that it would damage the health of the commercial satellite industry, it demonstrates the vulnerability of US-based commercial providers to government interference. Its mere existence as a possibility creates an incentive for foreign governments to promote their own domestic commercial-imagery industry. With the proliferation of satellite technology making it possible for universities to build and fund the launch of small imaging platforms, the possibility

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[26] Denette L. Sleeth, "Commercial Imagery Satellite Threat: How Can U.S. Forces Protect Themselves?" 12.
[27] Congressional Research Service, *Report for Congress: Commercial Remote Sensing by Satellite: Status and Issues*, 1.
[28] The exact reason for not exercising shutter control is unclear. The US military avoided traditional shutter control in 2001 to avoid harming the fledgling industry, and instead attempted a buy-to-deny form of shutter control in Afghanistan that was deemed too expensive to repeat in the future. Likely this reasoning carried over to the Iraq invasion in 2003.

exists that in the future companies seeking to launch imaging satellites will choose to base themselves offshore to escape US regulatory restrictions. The shutter-control restrictions, originally granted under PDD-23 in 1994, are at best irrelevant and at worst harmful to US industry.[29]

Only for extremely restricted periods of time and under extreme conditions will it be reasonable to consider creating any kind of imagery blackout in the future. It would require a combination of incentives and coercion applied by a variety of nations and organizations. For example, the application of a UN resolution combined with financial remuneration and a limited geographic and temporal scope for any ban might prove effective. Even so, this ban would likely be challenged in domestic and international courts by freedom-of-information advocates. Since an objective standard of when shutter control should be invoked does not exist, there is no guideline for when information should be withheld from the public.[30] This ambiguity in domestic US law creates uncertainty that would further complicate any broad effort to create an information blackout.

COMSATCOM

Small satellite constellations will provide a significant number of advantages over the current US military mix of legacy COMSATCOM and MILSATCOM. They offer substantially increased portability through the use of a small, mobile receiver with rebroadcast capability. Also, the potential bandwidth gains for most users operating in austere environments with poor viewing angles to geosynchronous orbit are enormous. Finally, the resiliency to attack of an architecture based on thousands of small inexpensive satellites is far greater than one based on

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[29] Presidential Decision Directive 23/National Security Council 23.
[30] Congressional Research Service, *Report for Congress: Commercial Remote Sensing by Satellite: Status and Issues*, 16.

a single satellite providing coverage for an entire theater. Another consideration is that data consumption is only going to increase, especially if another significant US military operation on the scale of Afghanistan or Iraq occurs, and the size of the MILSATCOM constellation is fixed for the near future due to the long development timelines of military satellites and associated ground structure. Despite the significant advantages offered by small satellite constellations and the vulnerability of the current architecture, the adoption of emerging small satellite technologies is likely to be slow due to legacy drag, conservative attitudes towards the adoption of new technologies, and lack of suitable purchasing models.

Legacy Drag

Legacy drag is a term used within the DOD to describe the organizational reluctance it has to acquiring new hardware because the existing hardware is still effective and the cost of acquiring and fielding new hardware is high.[31] The conservative behavior described by the term legacy drag will be a significant factor in the slow adoption of small satellite constellations in the COMSATCOM field within DOD. An example of legacy drag can be found in the DOD's 2014 *Satellite Communications Strategy Report*. In this report, the DOD listed three reasons for allowing the use of COMSATCOM over MILSATCOM. The final reason listed was "when the users' ground infrastructure (e.g., ground stations) will only operate over commercial satellites."[32] Instead of forcing these users to migrate to MILSATCOM to realize perceived cost savings, the DOD created an exception to accommodate users who had invested in incompatible commercial hardware. This same effect will

[31] Josef Koller, Office of the Under-Secretary of Defense for Space Policy, to the author, email, 23 January 2017.
[32] DOD, *Satellite Communications Strategy Report: In Response to Senate Report 113-44,* 8-9.

occur within the DOD on a much larger scale with respect to investments in MILSATCOM.

Investments in MILSATCOM architecture and other COMSATCOM ground systems will impede the adoption of rival revolutionary technologies. High-bandwidth, small satellite constellations will compete directly with bandwidth services already provided by existing MILSATCOM architecture. Despite small satellite constellations offering improved portability and bandwidth availability over existing MILSATCOM architecture, the DOD will find it difficult to invest in a competing architecture no matter how superior. This "sunk-cost-fallacy" behavior is often a resistive factor in the adoption of new things in the absence of a crisis.[33] The result of this behavior is that any solution that competes with MILSATCOM is not likely to be looked at seriously until the existing hardware reaches the end of its life expectancy. The first Wideband Global SATCOM (WGS) satellite, designed to be the mainstay of the MILSATCOM architecture upon its launch in 2008, is expected to have a 19-year lifespan.[34] With subsequent satellites in the DOD WGS constellation launching later, a need to replace the constellation due to age will not occur until nearly 2030. The need for additional throughput may overcome reluctance to adopt a competing solution as demand continues to increase beyond capacity, but legacy drag will remain a limiting factor.

Contract Issues

The partial centralization of COMSATCOM purchases within DISA/GSA will harm the adoption of emerging technologies because much of the cost savings achieved is through discounts based on volume

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[33] Daniel Kahneman, *Thinking Fast and Slow,* (New York, NY: Farrar, Straus and Giroux, 2013) 258.

[34] Turner Brinton, "Decision on Extra Fuel means Longer Lift for WGS Satellite," *SpaceNews*, 5 February 2008, http://spacenews.com/decision-extra-fuel-means-longer-lift-wgs-satellite/.

and length of contract. The CS3 contract length of 10 years, when options are included, is a deliberate trade-off by the DOD for cost savings in exchange for the ability to adopt new technologies. Since the CS3 contract includes options for complex solutions using a hybrid of MSS and FSS services, it will tie up budget resources that could be applied to new small satellite data constellations as they will likely be treated more as MSS than FSS type services.[35] The inability of the CS3 contract vehicle to provide an avenue for the adoption of emerging technologies during the contract period will prevent the DOD from being an early adopter of small satellite data constellations. DISA attempted to develop a method to allow for adding new providers to the contract during the development of the CS2 contract vehicle but found no way to do it under the IDIQ model of CS2. These limitations will likely not change for CS3.[36] Limited services were included under IT Schedule 70 in the CS2 contract, which does allow for the addition of new capabilities during a contract lifecycle, but it is typically limited to purchases of less than $550 thousand. [37] For example, a representative contract between GSA and COMSAT under IT Schedule 70 includes a maximum purchase limit of $500 thousand for various COMSAT hardware.[38] IT Schedule 70 will allow experimentation with new hardware as it is introduced if the providers of these capabilities choose to apply to the schedule process, or third parties operating outside the DISA/GSA process acquire their services directly. These limited opportunities will be the only option during the CS3 contract period for demonstrations of the new data constellations' usefulness.

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[35] General Services Administration, *Solicitation QTA0015SDA4003. Complex Commercial Satellite Communications (SATCOM) Solutions (CS3).*
[36] Sami Lais, "DISA, GSA lay out SATCOM buying Strategy," *Defense Systems*, 12 April 2010, https://defensesystems.com/articles/2010/04/08/satellite-industry-day.aspx
[37] General Services Administration website content, accessed 16 January 2017, https://www.gsa.gov/portal/content/203021.
[38] General Services Administration, *Federal Supply Service Pricelist, Contract GS-35F-0122X with COMSAT INC*, 13 September 2016.

Iridium as an Example

Iridium serves as a model of how future small satellite constellations could be leveraged. The DOD was an early adopter of Iridium through its investment in a gateway, and during Iridium's bankruptcy the DOD commitment to purchase $36 million a year in services made the bankrupt company viable.[39] DOD today remains a large part of the Iridium business model along with other government contracts. By being an early adopter of the technology, and a key supporter of it after bankruptcy, the DOD has ensured that Iridium remains responsive to its needs. For example, Iridium developed a system called "satellite time and location" which is specifically designed to augment the US Global Positioning System (GPS) in a jamming environment by providing a separate location signal that can be used to verify GPS accuracy.[40] The technology is specifically targeted at the US Government and was built into a chip-based solution that Iridium is marketing as an answer to DOD concerns over "spoofing" of GPS. Iridium recognizes the value and credibility that being a major provider to the DOD brings it and demonstrates this in its active efforts to address DOD concerns.

Iridium will also be an obstacle to the adoption of other small satellite technologies. The large investments that the DOD has made in Iridium handsets, the distributed tactical communications system, and a dedicated ground station represent capital investments in an ecosystem that limits DOD flexibility. Additionally, Iridium is the only global solution that offers handsets certified for classified discussion using an

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[39] Craig Mellow, "The Rise and Fall of Iridium."

[40] Iridium, *Press Release: Iridium Launches Breakthrough Alternative Global Positioning System (GPS) Service: Satellite Time and Location (STL) Solution Enables Positioning, Timing and Authentication to Augment GPS Technology for Critical Applications*, 23 May 2016, http://investor.iridium.com/releasedetail.cfm?releaseid=972324

NSA-approved communications-security sleeve.[41] This long history of cooperation and developing compatible technologies will create legacy drag, as DOD users will hesitate to abandon over a decade in integration efforts for a new technology. Iridium NEXT will further exacerbate this problem. The new system, entering service in 2017, will replace the aging original satellites and provide updated capabilities which will encourage the DOD to renew its current five-year contract worth $400 million expiring in 2018.[42] The Iridium constellations new capabilities are an improvement over the existing constellation, but designing for backwards compatibility forced the company to remain tied to its legacy technology. This means that Iridium's new constellation represents only a small improvement over its existing constellation. It will have data rates limited to 1.4 Mbps for its OpenPort-class terminals, compared to 50 Mbps for OneWeb's similar size terminal.[43] A renewal of the Iridium contract in 2018 for a similar period of performance will be an obstacle to the adoption of data constellation services and further reinforce ecosystem lock-in through continued capital investment.

Fragmentation and Pathfinders

Fragmentation within the DOD of COMSATCOM purchases increased cost but allowed for the adoption of new providers and a form of internal competition for the best technology. As each user with acquisition authority in the DOD sought its own solution to meet unique needs, a large variety of systems were adopted. This adoption of unique ground systems caused problems and continues to be one of the primary reasons that users are allowed to purchase COMSATCOM, but it did

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[41] Iridium, "Enhanced Mobile Satellite Services," accessed 16 January 2017, https://www.iridium.com/company/contact/usgovernment.
[42] Iridium Communications Inc, *Securities and Exchange Commission Form 10K*, 2015, 2.
[43] Iridium website content, accessed 19 April 2017, https://www.iridium.com/network/iridiumnext.

allow for experimentation.[44] Small satellite constellations will provide marked advantages over existing forms of COMSATCOM, and the ability of users to acquire COMSATCOM outside of the DISA/GSA contract vehicles would allow for some limited experimentation and adoption of the new technology. However, the ongoing centralization under DISA/GSA, with all of the advantages that creates, will limit the level of adoption and decrease the ability of users to purchase and experiment with the advantages of small satellite constellations.

Current Pathfinder efforts to improve DOD acquisition of COMSATCOM will provide limited benefits in future acquisition of data from commercial small satellite constellations. In its 2014 response to Congress, the DOD argued that "since MSS is generally based on a "pay as you use" sales model (much like cell phone service), the alternative procurement strategies suggested in the Senate report are not specifically relevant to MSS."[45] These Congressional strategies form the basis of the Pathfinder efforts. Despite this critique from the DOD, some of the pathfinder projects could yield valuable lessons for data constellations which will likely be considered MSS-type services. The Pathfinder project whereby the DOD purchases some portion of the transponders on a commercial satellite in development, effectively subsidizing development of the satellite, in exchange for future use of bandwidth may prove useful. The DOD could purchase a number of satellites in a constellation in exchange for a long-term service agreement. There are several obstacles to doing this, of course. The Pathfinder model on which it is based is not scheduled to end until after FY2019 when most of the satellites for the announced constellations will already be built or on orbit. Another issue is that much of the money that would be available

[44] DOD, *Satellite Communications Strategy Report: In Response to Senate Report 113-44,* 8-9.
[45] DOD, *Satellite Communications Strategy Report: In Response to Senate Report 113-44,* 1.

to execute this plan will be tied up in contracts with traditional providers or legacy systems, such as Iridium. Finally, since COMSATCOM satellite constellations are only effective when the entire constellation is on orbit the DOD will need to commit to a given architecture before it has proven itself technically or commercially viable. The DOD did do this with Iridium by investing in a dedicated gateway prior to the initial launch of the system, but the lack of success that the Iridium constellation had commercially is unlikely to encourage the government to invest the sums necessary to make such an agreement attractive to a commercial provider.

During its pathfinder-development process, SMC discovered that it needed a ground terminal that could adapt to different provider needs.[46] The problems inherent in the variety of proprietary technologies that current COMSATCOM providers have developed for their systems will be magnified with satellite constellations. Space X and OneWeb are likely to take drastically different approaches to the development of their ground segments, given the unique challenges that they each have to overcome in their constellation design. This will make it extremely difficult and probably cost prohibitive for the DOD to solicit the design of a universal data receiver for small satellite constellations as it is currently attempting to do with traditional providers.

Inability to develop provider agnostic hardware will dictate investing in a single provider. Once the DOD purchases enough ground-segment hardware and integrates it into enough military systems to make the purchase worthwhile, the DOD will be effectively locked in. The same factors that will make it difficult for the DOD to separate itself from Iridium will create a financial and logistical obstacle to choosing a new data provider. SMC's pathfinder efforts have been valuable in identifying lack of ground segment interoperability as one of the largest

[46] Air Force Space Command. *Pathfinder 3 Request for Information: Solicitation Number 16-076,* 20 May 2016.

factors preventing the DOD, as a global user, from leveraging regional satellite networks and not just providers with global coverage.

MILSATCOM as an Obstacle

Reliance on a MILSATCOM network built to a standard that is incompatible with commercial systems limits DOD flexibility. Unlike in the ISR industry where DOD dominates the market, in the COMSATCOM industry the DOD represents a very small fraction of the total industry revenue. In 2012, the DOD spent $846.4 million on FSS and $299.2 million on MSS.[47] The total market for FSS and MSS-type services in 2012 was $17.1 billion and $3.3 billion respectively.[48] DOD then represented only 5.6% of the global market for COMSATCOM. Since this expenditure is not concentrated regionally but dispersed globally, in line with DOD responsibilities, the DOD does not provide enough economic incentive for the commercial industry as a whole to move towards DOD standards. Instead, the DOD must move towards making its hardware interoperable with as many commercial systems as possible so that its ground-segment hardware is not a limiting factor.

Incompatibility of MILSATCOM ground-segment hardware limits resiliency in the DOD SATCOM architecture. The long lead time in developing MILSATCOM systems means that they are designed to unique standards with customized ground-segment hardware that is incompatible with commercial systems. This lack of compatibility has been an enduring complaint in the commercial industry.[49] Future DOD MILSATCOM architecture design must include considerations of interoperability to promote resiliency. This can be accomplished by

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[47] U.S. Strategic Command, *Fiscal Year 2012 Commercial Satellite Communications Usage Report,* 5, 31.
[48] Tauri Group, *State of the Satellite Industry Report, Satellite Industry Association*, September 2015, Slide 11.
[49] Ron, Samuals, Open Letter, Seven Ways to Make the DoD a Better Buyer of Commercial SATCOM.

including some degree of COMSATCOM interoperability as a requirement for future MILSATCOM systems. Promoting this type of interoperability will be difficult since the commercial industry itself is fragmenting, but the DOD can assist in driving a technology standard.

The DOD has been criticized for its poor cost comparisons between COMSATCOM and MILSATCOM within the commercial industry.[50] These cost comparisons have driven DOD decisions to rely on MILSATCOM and avoid committing to purchasing too much COMSATCOM. The fact that a baseline comparison exists does help the DOD in developing a strategy that incorporates COMSATCOM, even if the comparison is highly criticized. Concerning the advantages of small satellite constellations to MILSATCOM, the DOD will have difficulty developing an adequate comparison since there is no existing DOD constellation to serve as a benchmark. Expenditures on Iridium provide the closest probable test case. The current fixed-price contract with Iridium, valued at $400 million for a five-year term ending in 2018, serves to primarily provide voice communications using handheld receivers.[51] For example, the Iridium constellation supports data at the rate of only 2,400 bps; and, even though the Iridium NEXT upgrade occurring in 2017 will increase this to a maximum of 1.4 Mbps, this is still only a fraction of the 50 Mbps to 1 Gbps or more that OneWeb and SpaceX are promising.[52,53] Placing an accurate and precise value on the high data rates that future constellations will provide to vehicle-mounted Soldiers, Sailors, Airmen, and Marines will be a difficult challenge for the DOD to overcome.

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[50] Ron, Samuals, Open Letter, Seven Ways to Make the DoD a Better Buyer of Commercial SATCOM.

[51] Iridium Communications Inc, *Securities and Exchange Commission Form 10K*, 2015, 2.

[52] Iridium Corporation, "Iridium NEXT: Changing the future of Satellite Communications NOW," June 2016, https://www.iridium.com/network/iridiumnext.

[53] Peter B. Selding, "Virgin, Qualcomm Invest in Oneweb Satellite Internet Venture." *SpaceNews*, 15 January 2015. http://spacenews.com/virgin-qualcomm-invest-in-global-satellite-internet-plan/>.

SUMMARY

There are challenges and inconsistencies in US Government and military policy towards both remote sensing and COMSATCOM that will be obstacles to maximizing the use of small satellite constellations. For remote sensing platforms, these challenges will include the licensing process, the dependence the industry has shown on government contracts, and the difficulty of breaking the usage paradigm that commercial imagery operates under within the US Government. The DOD will eventually take advantage of these new remote sensing platforms if they can develop commercial business models capable of supporting themselves without government funding. The depth of funding available is limited, and operating costs are likely to be high. For the time being, these emerging capabilities are being developed on the promise of future potential. If this potential fails to materialize, as it did in the past, then these promising remote sensing constellations will be unable to survive on government funds alone.

Legacy drag, conservative attitudes towards the adoption of new technologies, and lack of appropriate purchasing models will be the biggest challenges to the adoption of COMSATCOM small satellite constellations. These three factors will not prevent the DOD from eventually integrating small satellite data constellations into its COMSATCOM architecture, but it will substantially slow it down. The length of the gap between the deployment and its adoption will be determined by a combination of the factors mentioned above.

Chapter 6

Conclusion

Someday, I hope to hoist my own grandchildren onto my shoulders. We'll still look to the stars in wonder, as humans have since the beginning of time. But instead of eagerly awaiting the return of our intrepid explorers, we'll know that because of the choices we make now, they've gone to space not just to visit, but to stay -- and in doing so, to make our lives better here on Earth.

- President Barack Obama October 11, 2016

In this thesis, I examined the impact of policies, developmental models, and purchasing agreements on the adoption of small satellite constellations for remote sensing and communications by the US military. This research suggests that no single policy or strategy alone will effectively address the numerous limitations to small satellite constellation adoption identified in the previous chapters. That stated, there are several ways by which the US military might maximize utilization of emerging small satellite constellations in remote sensing and communications. In this final chapter, I provide policy and acquisition changes that could be made to posture the US military to utilize small satellite constellations effectively.

Maximizing Utilization

There are several advantages to the availability of small satellite constellations that apply to both remote sensing and COMSATCOM platforms. The new constellations will promote resiliency of the US owned space segment, provide a model for manufacturing satellites cheaply in quantity, and demonstrate the effectiveness of a disruptive new technology. The US Government needs to foster this technology for the advantages it will provide. One way this can be done is through adopting a Civil Reserve Airfleet (CRAF) model for US based space platforms.

Adopting the Civil Reserve Air Fleet Model

CRAF is a voluntary cooperative program between the Department of Transportation, DOD, and US Airlines. The program was established following the Berlin airlift in 1951 as a way to provide "supplemental airlift to support a major national defense emergency."[1] The idea behind it is a public-private partnership where the government guarantees a minimum level of annual business to civilian airlines in exchange for the ability to mobilize them to support the military in times of crisis. Mobilization proceeds in stages based on aircraft need and has only been activated twice in history. The first time was to support the first Gulf War and the second time was to support Operation Iraqi Freedom from February 2003 to June 2003.[2] Essentially "the CRAF program meets the military's mobilization requirements while saving taxpayers billions of dollars by foregoing the cost of procuring a government fleet to meet those requirements."[3] A 1994 Rand study estimated that the CRAF program saved the US Government $128 billion dollars from 1951 to 1994 in 2009 dollars.[4] Prior to 9/11, the US military did $600 million a year in business with CRAF members; after 9/11 that amount increased to over $3 billion a year.[5] This program has been a valuable partnership for US-flagged carriers, supporting the industry while meeting US military wartime-surge requirements.

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[1] Department of Transportation, "Civil Air Fleet Allocations," accessed 1 February 2017, https://www.transportation.gov/mission/administrations/intelligence-security-emergency-response/civil-reserve-airfleet-allocations.
[2] Christopher Bolkcom, *Civil Reserve Air Fleet*, Congressional Research Service, 18 October 2006, 3.
[3] Jerry F. Costello, Chairman of House Subcommittee on Aviation, *Hearing on the economic viability of the Civil Reserve Air fleet Program*, 111th Cong., 111-30, 13 May 2009.
[4] Jerry F. Costello, *Hearing on the economic viability of the Civil Reserve Air fleet Program*.
[5] Gen. Duncan J. McNabb, Commander U.S. Transportation Command, *Hearing on the economic viability of the Civil Reserve Air fleet Program*, 111th Cong., 111-30, 13 May 2009.

In wartime, the US military and Intelligence agencies have similar surge requirements for SATCOM and imagery to those that the CRAF supplies for transportation needs. The dollar amounts spent on CRAF during peacetime are very close to those that are currently spent on commercial satellite contracts today between COMSATCOM and remote sensing. The public-private partnership model of CRAF applied to space would solve a number of overarching issues that have appeared in this research. First, it would remove the uncertainty of future-year funding that has led to the consolidation of the remote sensing industry down to just one company. Second, it would give the US commercial providers an incentive to consider military security and compatibility requirements when developing satellites, an ongoing problem that prevents the military from rapidly switching between MILSATCOM and COMSATCOM providers. Third, it would ensure the availability of US flagged satellites that could be quickly leveraged to expand capacity when it inevitably grows during periods of national crisis, as this research demonstrated is historically the case. Finally, creating a Civil Reserve Space Fleet (CRSF) would allow the US military to formally incorporate the US commercial architecture into its wartime planning, creating an organizational incentive to properly integrate and balance the size and capabilities of the MILSATCOM fleet with commercial capabilities.

Applying the CRAF model to space is not a revolutionary idea and its benefits are recognized by the senior leadership in OSD.[6] DOD has explored adopting the CRAF model but does not have the level of broad, high-level government support necessary to make it happen.[7] The idea would need the support of a broad coalition in Congress as well as the Secretaries of Commerce and Defense, the Director of National

[6] Josef Koller, Office of the Under-Secretary of Defense for Space Policy, to the author, email, 23 January 2017.
[7] Josef Koller, Office of the Under-Secretary of Defense for Space Policy, to the author, email, 23 January 2017

Intelligence, and the GSA to have any possibility of success. In order to begin building that consensus, the idea would need a senior advocate within the DOD. The Secretary of the Air Force (SECAF) is officially the Executive Agent (EA) for Space charged with "developing the space power needed to achieve national security objectives," but in reality, those duties fall almost entirely on a Deputy Under Secretary for Space Programs within the SECAF office.[8] Without much more senior advocacy, preferably the Secretary of Defense, or an unlikely national emergency drawing attention to space assets, the idea of a CRSF is unlikely to gain the traction necessary for implementation. As a result, the most likely approach to ensure US military success in leveraging emerging space technology is through a series of incremental improvements to the current process.

Incremental Improvements

There are a number of improvements that can be executed by the DOD in the area of COMSATCOM without the significant level of interagency coordination that adopting a CRAF model would require. Current DOD policy is to maximize utilization of MILSATCOM and utilize commercial assets only when military assets are unavailable.[9] This decision makes fiscal and operational sense because the DOD has calculated that MILSATCOM is significantly cheaper than COMSATCOM.[10] The CEOs of the major COMSATCOM companies have previously argued with the DOD's cost calculations and blamed some of the distorted cost on DOD's short-term, spot-leasing IDIQ acquisition

[8] DOD Directive, memorandum, subject: DoD Executive (EA) for Space, Number 5101.02E, 25 January 2013.
[9] Government Accountability Office, Defense Satellite Communications, (Washington, DC: GAO, July 2015), 13.
[10] Department of Defense. Satellite Communications Strategy Report: In Response to Senate Report 113-44 to Accompany S.1197 NDAA for FY14. Washington, DC: Office of the Chief Information Officer, 14 August 2014. Pg 8

approach.[11] The DOD has addressed many of these cost concerns through the CS2 and CS3 contract vehicles, which both significantly increased the base period. According to US Air Force General John Hyten "The DOD saved approximately 40 percent versus annual spot leasing with [these] long-term deals."[12] That long-term contracting has resulted in such significant savings in costs implies that COMSATCOM should become a permanent part of the DOD SATCOM architecture to avoid short-term leasing costs. If COMSATCOM were a long-term contracted asset, then it would need to be more efficiently utilized. An overflow-only policy no longer makes sense. An overflow-only policy prevents effective integration of COMSATCOM into the overall SATCOM architecture by disincentivizing the development of compatible hardware by commercial companies and the military. It makes more sense to create a tiered structure where certain types of communications flow over MILSATCOM, and others are automatically tasked to leverage contracted capabilities fully.

Protection for these lower-tier communications is achieved by utilizing a mixture of satellite architectures. Small satellite constellations have several advantages over traditional FSS. The low orbit, quantity of satellites, and ease of replacement mean that these constellations will have an inherent resiliency not possible with dedicated Geosynchronous platforms. They will also greatly increase the quantity of available bandwidth. Rather than assuming that all military data usage needs to be inherently protected, lower-tier communications should focus on leveraging diversified architecture to achieve overall system resiliency by complicating adversary targeting.

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[11] Ron, Samuals, Open Letter. Seven Ways to Make the DoD a Better Buyer of Commercial SATCOM.
[12] Anne Wainscott-Sergent, "Defense Eyes Lowe Risk High-Throughput Future." *Satellite Today*, September 2016. http://interactive.satellitetoday.com/via/september-2016/defense-eyes-lower-risk-high-throughput-future/.

The large quantity of satellites being produced by these small satellite COMSATCOM companies is another opportunity. OneWeb is in the process of producing its first 900 satellites at a factory in Florida.[13] For comparison, a typical satellite production facility has at most a handful of satellites under production at any one time. Former Deputy Assistant Under Secretary Doug Loverro believes that the real innovation that these small satellite companies are creating is the "invention of the assembly line (for space products), which will precipitously drop the cost of satellite construction."[14] He believes that the DOD can leverage these techniques and "may choose to do constellations of OPIR (Overhead Persistent Infrared) satellites using those same techniques."[15] This would be a radical departure from the current DOD satellite-procurement process. The latest generation of OPIR satellites cost $1.1 billion each, and the third satellite of this generation launched only in January 2017 after nearly 20 years in development.[16] The DOD may choose to develop its own constellations, in that case, the "ultimate goal is to use the manufacturing capability they create," instead of relying on commercially developed constellations.[17]

Unlike the COMSATCOM industry, the remote sensing industry is extremely dependent on domestic policy and US Government business. The NGA contract award process has driven industry consolidation down to just a single company, DigitalGlobe. New entrants into the market are all adopting an approach based on constellations of small satellites that produce good-enough imagery, combined with rapid refresh rate, to

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[13] OneWeb, "OneWeb Satellites Unveils the World's largest High Volume Satellite Manufacturing Facility," 19 April 2016, http://oneweb.net/press-releases/2016/oneweb-satellites-unveils-the-worlds-largest-high-volume-satellite-manufacturing-facility.
[14] Douglas Loverro, interview 13 January 2017.
[15] Douglas Loverro, interview 13 January 2017.
[16] Mike Gruss, "Lockheed Martin Examines Cost-cutting Options for SBIRS," *SpaceNews*, December 8 2014. http://spacenews.com/42887lockheed-martin-examines-cost-cutting-options-for-sbirs/
[17] Douglas Loverro, interview 13 January 2017.

compete with the exquisite high-resolution imagery provided by DigitalGlobe. For these new entrants into the market to survive, they must develop an international market for their products. The US regulatory environment hampers this through the licensing, inspection, and foreign-sales review process.

The US regulatory environment is hampering the growth of domestic space-based ISR providers and promoting reliance on the US government. In a recent Op-ed Walter Scott, the founder of Digital Globe argued that "it's time to rethink the basic premise underlying commercial remote sensing regulation."[18] The industry is at a competitive disadvantage as the result of the unnecessary bureaucracy surrounding the entire licensing process. Beginning with the interagency-review process for initial licensing to the review of foreign-sales agreements, the entire system is burdensome and unnecessary. Resolution restrictions have been set low enough that no realistic commercial market exists for anything better, and small satellite constellations are relying on faster refresh rates, rather than higher resolution, for their business models – something that the security review process, with its historical focus on image quality, will have difficulty adjusting to.

Changes to the standard for security review by Mr. Loverro during his tenure at OSD will help accelerate the approval of new remote sensing capabilities, but these modificaitons do not go far enough. The review process should be just that, a review. The national security community needs to adjust to developing risk-mitigation strategies rather than simply adopting a risk avoidance strategy by denying a license because the technology represents a perceived national security threat. Mr. Loverro added the requirement that the US must have the "ability to control export and development" of a particular technology in order to

[18] Walter Scott, "US Satellite imaging regulations must be modernized," *SpaceNews*, 29 August 2016, http://spacenews.com/op-ed-u-s-satellite-imaging-regulations-must-be-modernized/.

impose restrictions.[19] This requirement is a tacit acceptance that the US no longer has a monopoly on many space technologies; and denying a license because it represents something new, may simply drive that capability off shore. The entire process of pre-approval on the basis of national security in order to issue a license is increasingly irrelevant.

Foreign-sales approval is another factor harming the remote sensing industry's ability to compete. The founder of Digital Globe has argued that "US firms must wait months for government approval to enter into larger foreign imagery sales agreements, creating a competitive disadvantage."[20] His complaint is valid. The US Government Office of Foreign Assets Control (OFAC) maintains a sanctioned entities list that lists any individuals or entities subject to trade sanctions.[21] As long as companies owning remote sensing platforms are in compliance with this list, it is difficult to see how national security is furthered by a lengthy security review process that puts the already weak US remote sensing industry at a further disadvantage. Changing this regulation to a notification-only process would serve the industry while keeping the US Government aware of foreign obligations. Alternatively, the agencies involved in the review process could establish a finite list of foreign entities, similar to what OFAC does, that require pre-approval. Modifications to this list would need cabinet-level approval and consensus among the reviewing agencies to avoid arbitrary additions. Adopting either one of these strategies would remove the competitive disadvantage under which the US remote sensing industry currently operates and bring these policies in line with US national policy directives directed at promoting US commercial space.

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[19] Douglas Loverro, interview 13 January 2017.
[20] Douglas Loverro, interview 13 January 2017.
[21] US Department of Treasury, "Sanctions," accessed 1 Feb 2017, https://www.treasury.gov/resource-center/sanctions/Pages/default.aspx.

Licensing as a whole is still something that is necessary, though only after it is modified to be less burdensome and opaque. Some companies have added a remote sensing capability to a platform just "so they can go through the interagency process because no other licensing process is available to them."[22] Possessing a license to operate a satellite in space from the US Government is clearly desirable, but it does not have to be a burdensome process. Removing the inspection requirement, license pre-approval security review, and foreign-sales review would greatly aid the existing and emerging commercial remote sensing markets break their dependence on the US Government for funding. Adopting a risk-mitigation strategy, rather than the risk-avoidance strategy that the current review process is built upon, is the path that the interagency-review process should take. Maintaining the right, under the license agreement, to exercise shutter control is something that has never been used, but should remain, because it establishes an important legal precedent to exercise control of US-based providers that may someday be necessary. When it was first authorized shutter control caused concern, but the hesitancy to use it has removed those concerns. As a result, it is not a something that is substantially harming the industry's ability to compete internationally.

Another limiting factor that will harm the US military's ability to leverage small satellite remote sensing technology is the current usage paradigm. Changing the attitude that commercial imagery is foundational or that Google Earth is good enough will be a challenge. Military users often either rely on low-quality, outdated Google Earth imagery or request classified assets.[23] There is a vast, under-utilized middle ground that is the result of lack of education, perceived lack of

[22] Minutes of Advisory Committee on Commercial Remote Sensing (ACCRES), 21 September 2016, 5.
[23] Authors experience as an Army Space officer for 11 years and as Operations officer for the Army's only Space battalion.

availability, and the belief that Google Earth is good enough. Therefore, the NGA should focus on developing distribution timelines for commercial imagery that allow it to be operationally relevant. This can be done by developing a distribution architecture built on high-bandwidth commercial access for the tactical user. In addition, the DOD and interagency community need to change the attitude towards commercial imagery as foundational and focus on building or leveraging existing web-based tools.

Denying Adversary Use

Denying potential adversaries the use of data and images from small satellite constellations will be extremely difficult in the future. For remote sensing platforms, the licensing process provides some legal recourse for the US Government to stop US-based providers from taking or releasing imagery; but the availability of foreign commercial, private, and national assets capable and willing to fill the gap makes imposing any restrictions counter-productive. Under unique circumstances, like those during the first Gulf War where Spot Image agreed not to sell imagery and the Iraqi regime was the object of a broad international coalition operating under a UN mandate, it may be possible to impose a voluntary blackout through diplomacy.[24] Doing this would require the cooperation of a highly-distributed media industry and many different corporate entities. Even then, the embargo could only be reasonably applied for a very short duration over a limited geographic region.

Executing a broad diplomatic strategy to restrict the release of imagery to an adversary would take significant preparation, which would need to be conducted in advance. If the US has the largest share of the remote sensing industry, then the task is made easier because of the restrictions still present in the existing license structure. Foreign

[24] Denette L. Sleeth, "Commercial Imagery Satellite Threat: How Can U.S. Forces Protect Themselves?" 12.

companies and countries would also have to be in agreement for any ban to be effective. For this to occur, the ban would need the support of an international organization with some recognized legal authority over space assets that could enforce it. Only the United Nations has anything like this ability. The United Nations does not currently have any permanent legal basis for prohibiting the release of imagery, though it does have legal guidelines for the management of remote sensing platforms.[25] Proposing an embargo on imagery should be something the US should include in any future UN resolution that presupposes military action against a targeted state.

Restricting the sale or acquisition of imagery to non-state actors is almost impossible. As early as 2006, insurgents in Iraq were shown to be using Google Earth images to target the US military in Iraq.[26] Recognition that "access to such images lowers the [terrorism] threshold" has been present since shortly after Google Earth's creation.[27] However, stopping non-state actors from accessing imagery entirely is not realistically possible. The US could push for only low-resolution images to be taken of key installations in the United States and abroad, but this would require identifying all sensitive locations publicly, which would then make them natural targets for foreign-government remote sensing platforms. Already, Google Earth has been utilized by various users to identify sensitive US military installations abroad including a CIA drone base in Pakistan.[28] Asking for images of known installations to be blurred to a relatively low resolution by aggregators of imagery such as Google Earth is possible; but it only raises the threshold for obtaining

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[25] United Nations Office for Outer Space Affairs, *United Nations Treaties and Principles on Outer Space, related General Assembly Resolutions and other Documents*, 38. http://www.unoosa.org/pdf/publications/ST_SPACE_061Rev01E.pdf

[26] Open Source Center, "The Google Controversy-Two Years Later," 20 July 2008, available at http://nsarchive.gwu.edu/NSAEBB/NSAEBB404/docs/23.pdf

[27] Open Source Center, "The Google Controversy-Two Years Later."

[28] Jeremy Page, "Google Earth reveals secret history of US base in Pakistan," *The Times UK*, 19 February 2009, http://www.thetimes.co.uk/tto/news/world/asia/article2609737.ece.

imagery; it does not prevent potential terrorists or insurgents from obtaining it altogether.

Preventing adversaries from benefiting from the advantages of data constellations is even more difficult. Technically it should be possible for a data-services provider to deactivate all ground terminals in a designated region that are not on a desired list. Politically this is unfeasible, except in a scenario similar to that mentioned above where the targeted region or entity is subject to international sanction. Doing so would create additional challenges even if a data services provider chose to cooperate. This research has shown that the DOD historically struggles to gain an accurate picture of spending on COMSATCOM. USSTRATCOM's *Fiscal Year 2012 Commercial Satellite Communications Usage Report,* was published on 6 April 2015, 20 months following the end of FY12.[29] Obtaining IDs for every terminal in a theater of operations, from every government, coalition, and non-governmental organization using a data device linked to a small satellite constellation is not realistically possible, when simply calculating internal expenditures requires such an extended timeline. Even identifying those belonging to the DOD that are operating in a given theater under a fragmented contracting structure is almost certainly unrealistic. Preventing adversary leveraging of COMSATCOM provided by small satellite data constellations is not something that can be done by pressuring the data provider.

Localized active measures such as jamming are a possibility but are easily countered. Any airborne or terrestrial jamming source would have to be very powerful to jam even a relatively small area of a few square kilometers and is easily countered. Simply putting a physical barrier between the receiver and the jammer, while preserving line-of-sight to the satellite, would restore communications.

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[29] U.S. Strategic Command, *Fiscal Year 2012 Commercial Satellite Communications Usage Report,* 1.

Jamming the signal source as a method of denying the use of COMSATCOM from small satellite constellations will not be as easy as it is for traditional fixed satellite services. Iran demonstrated how easy jamming traditional FSS can be in 2009 when it jammed the satellites carrying Voice of America and Radio Free Europe broadcasting into Iran.[30] This is a relatively simple problem when a single, nearly stationary satellite (when viewed from Earth) is the source of transmissions or data. Small satellite constellations operating in low Earth orbit, moving rapidly across the user's field of view, in multiple orbital planes, and crosslinked for data transmission to the nearest ground site, presents a completely different problem. This difficulty in jamming does make small satellite data constellations an attractive alternative to using traditional FSS for US forces.

Denying an adversary use of small satellite constellations is something that would require international political accord and is possible only with remote sensing systems. State actors subject to international sanction and military action could be denied access for short intervals in a confined geographic area, but non-state actors can only be discouraged, not stopped. The cost in effort and political capital required to execute an effective international ban needs to be weighed against the operational benefits of doing so.

Summary

The US military and the broader US Government are not prepared for the availability of a disruptive new space technology like small satellite constellations. In fairness to the government, satellite constellations represent a rare disruptive technology that will upset the entire space industry's business model. Current contracting models for

[30] Voice of America News, "Iran Jams Satellites to Block transmission by VOA, BBC," 30 December 2009, http://www.voanews.com/a/iran-jams-satellites-to-block-transmissions-by-voa-bbc--80352412/416809.html

COMSATCOM are still struggling with how to manage traditional COMSATCOM efficiently and will struggle more with adapting to the new technology. The remaining major remote sensing company is entirely dependent on the government, and new entrants are developing the same dependency. They also operate under unnecessary restrictions as part of the licensing process that will harm their ability to break this dependence.

Adopting a new technology is always a difficult process. The US military has "always been a slow adopter because lives are on the line, the danger [today] is that slow adoption will now put lives on the line."[31] Failing to quickly adopt a new technology that promises to provide advances in data throughput and intelligence capability will give an advantage to potential adversaries that do. The US military, like martial organizations throughout history, has always been conservative in adopting new technologies, but this has not been a problem because "the rest of the world was slower."[32] This is no longer true as the drag effect created by legacy architecture prevents the quick adoption of replacement technologies. Potential enemies, unencumbered by this, will be quick to adapt; and will put the US military at a disadvantage. This is especially true for space because, according to Mr. Loverro, "of all the conservative adopters in DOD the space guys are the slowest."[33] Looking forward, relatively small changes could accelerate the pace of adoption though institutional inertia will present a difficult challenge.

[31] Douglas Loverro, interview 13 January 2017
[32] Douglas Loverro, interview 13 January 2017
[33] Douglas Loverro, interview 13 January 2017

Table 9: Summary of Recommendations

Recommendation	Addresses	Challenges to implementation	Effectiveness/Likelihood of Implementation
Adopt Civil Reserve Air Fleet model to Space (both Remote Sensing and COMSATCOM)	Removes uncertainty in future year funding	Requires broad high level support in the DOD and Congress	High/Low
	Incentivize compatibility with DOD		
	Incentivize inclusion of security features		
	Ensure Availability during periods of National Crisis		
Accept COMSATCOM as Permanent Part of Military SATCOM architecture	Encourages DOD to develop compatible ground segment hardware	Requires change of MILSATCOM first mentality	High/Medium
	Prioritizes high value communications on secure platforms	Requires development and adoption of compatible ground segment hardware	
	Creates permanent user base in DOD for COMSATCOM		
Leverage Small Satellite Manufacturing Techniques developed by Industry	Dramatically decrease cost per satellite		Medium/ Medium
	Decrease production time		
	Greatly increase quantity, increasing resiliency		
Discard foreign sales review on remote sensing satellites	Increases competitiveness in Global Marketplace	Congressional Authorization	Low/Medium

	Potentially decreases reliance on US Government sales		
Adopt risk mitigation strategy rather than risk avoidance for remote sensing platform licensing	Bureaucratic burden of regulation	Congressional Authorization	Low/Low
Change usage paradigm for commercial remote sensing away from foundational mentality	Idea that commercial imagery is not useful as an intelligence source	Current architecture of imagery request and distribution process	Medium/High
Lower multispectral imagery limit from 1-meter	Future competitive concerns that will arise from current 1-meter limit on multispectral	Requires buy-in from interagency national security review process	Low/High

Source: Authors original work

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